Mineral Development Division
Department of Mines
Government of Newfoundland and Labrador

CURRENT RESEARCH

Report 88 – 1

Compiled and Edited by
R.S. Hyde, D.G. Walsh and R.F. Blackwood

St. John's, Newfoundland
March, 1988

PREFACE

This publication presents the results of the 1987 research program of the Mineral Development Division. During 1987, the Division carried out a large number of geological, geochemical, geophysical and mineral-deposit studies in its continuing effort to provide a geoscientific database for mineral exploration and mineral-resource management. Location of these projects is shown in the map at the beginning of this report, and preliminary results are presented in papers prepared by individual project leaders. Final results will eventually be published as separate reports in the Division's various report series.

Many of the projects described herein were carried out under the Canada – Newfoundland Mineral Development Agreement (1984 – 1989), as indicated in the individual reports. The Geological Survey of Canada also carried out a number of projects in the province under the Agreement; we thank GSC for permission to include abstracts of these reports, which will appear in GSC Current Research (GSC Paper 88-1).

The Canada – Newfoundland Mineral Development Agreement comes to an end on March 31, 1989. Many of the projects funded under the Agreement will concentrate next year on the preparation of final maps and reports, rather than on the acquisition of new data. We therefore anticipate a somewhat-reduced field program in 1988, to be followed by a renewed effort under an anticipated new Agreement in 1989.

B.A. Greene
Director
Mineral Development Division

EDITING, LAYOUT AND DRAFTING

Senior Geologist R.F. BLACKWOOD

Editor R.S. HYDE

Copy Editor D.G. WALSH

Typesetting B. STRICKLAND
J. MATTHEWS

Word Processing J. MATTHEWS
D. DOWNEY
B. STRICKLAND
J. MORGAN
K. CONNORS
D. PEAVY

Supervisor, Cartographic Services K. BYRNE

Drafting D. LEONARD
T. PALTANAVAGE
K. STEINHAUER
S. SHORT

Publications of the Mineral Development Division are available through the Publications and Information Section, Mineral Development Division, Department of Mines, P.O. Box 4750, St. John's, Newfoundland, A1C 5T7.
Telephone: (709) 576-3159
Telex: 016-4724

Any reader who would like to write a rebuttal to, or discussion of, any report contained in this volume is invited to submit it to the editor by November 1, 1988, to be considered for inclusion in Report 89−1.

CONTENTS

Page

REGIONAL GEOLOGY – LABRADOR

1. **B. Ryan, D. Lee and D. Dunphy** The discovery of probable Archean rocks within the Labrador arm of the Trans-Hudson Orogen near the Labrador – Quebec border (NTS 14D/3,4,5 and 24A/1,8) 1

2. **Andrew Kerr** Geochemical characteristics and mineral potential of specialized granitoid plutons in the Trans-Labrador batholith, eastern Labrador 15

3. **J.N. Connelly** An investigation of the margin of the Lac Joseph allochthon, Grenville Province, southwestern Labrador 37

4. **R.J. Wardle, B. Kjarsgard, L.V.J. Crisby, C. Anstey, M. Harris and B. Lawlor** Geology of the Goose – Pinus rivers area (13F/3, 4, 5 and 6), central Grenville Orogen, Labrador 49

5. **Charles F. Gower, Timothy Van Nostrand and John Smyth** Geology of the St. Lewis River map region, Grenville Province, eastern Labrador 59

REGIONAL GEOLOGY – NEWFOUNDLAND

6. **W.D. Boyce, J.S. Ash and I. Knight** Biostratigraphic studies of Ordovician carbonate rocks in western Newfoundland, 1987 75

7. **J. W. Botsford** Geochemistry and petrology of Lower Paleozoic platform-equivalent shales, western Newfoundland 85

8. **J.T. van Berkel and K.L. Currie** Geology of the Puddle Pond (12A/5) and Little Grand Lake (12A/12) map areas, southwestern Newfoundland 99

9. **Brian H. O'Brien** Relationships of phyllite, schist and gneiss in the La Poile Bay – Roti Bay area (parts of 11O/9 and 11O/16), southwestern Newfoundland 109

10. **Stephen Colman-Sadd** Geology of the Snowshoe Pond (12A/7) map area 127

11. **M.A.J. Piasecki** A major ductile shear zone in the Bay d'Espoir area, Gander terrane, southeastern Newfoundland 135

12. **W. Lawson Dickson** Geology and mineralization in the Hungry Grove Pond (1M/14) map area, southeastern Newfoundland 145

13. **Pat O'Neill and Ian Knight** Geology of the east half of the Wier's Pond (2E/1) map area and its regional significance 165

14. **W.D. Boyce, J.S. Ash, P. O'Neill and I. Knight** Ordovician biostratigraphic studies in the Central Mobile Belt and their implications for Newfoundland tectonics 177

15. **S. Henry Williams** Middle Ordovician graptolites from central Newfoundland 183

16. **J.R.Meyer, P.L.Dean and C.R. Barnes** Conodont ages for three carbonate samples from Middle Ordovician cherts and shales in central Newfoundland 189

17. **Sean J. O'Brien and Ian Knight** The Avalonian geology of southwest Bonavista Bay: portions of the St. Brendan's (2C/13) and Eastport (2C/12) map areas 193

18. **Ian Knight and Sean J. O'Brien** Stratigraphy and sedimentology of the Connecting Point Group and related rocks, Bonavista Bay, Newfoundland: an example of a Late Precambrian Avalonian Basin 207

ECONOMIC GEOLOGY

19. **R.R. Miller** Yttrium (Y) and other rare metals (Be, Nb, REE, Ta, Zr) in Labrador 229

20. **J.R. Meyer and P.L. Dean** Industrial minerals and follow-up of lake- and stream-sediment geochemical anomalies in Labrador 247

21. **P.W. Delaney and A.F. Howse** Dolomite evaluation project 261
22. **A.F. Howse** Marble Assessment Project—1987 273
23. **J. Tuach, P.L. Dean, H.S. Swinden, C. O'Driscoll, B.F. Kean and D.T.W. Evans** Gold mineralization in Newfoundland: a 1988 review 279
24. **C. M. Saunders and J. Tuach** K-feldspathization, albitization and gold mineralization in granitoid rocks: the Rattling Brook alteration system, western White Bay, Newfoundland 307
25. **B.F. Kean and D.T.W. Evans** Regional metallogeny of the Victoria Lake Group 319

QUATERNARY GEOLOGY

26. **Martin Batterson, Angus Simpson and Sharon Scott** Quaternary mapping and drift exploration in the Central Mineral Belt (13K/7 and 13K/10), Labrador 331
27. **Margot Emory-Moore, Steve Solomon and Dennis Dunsmore** Placer potential of Fox Island River and east-central Port au Port Bay: a preliminary assessment 343
28. **David Proudfoot** Quaternary geology of the Mount Sylvester (2D/3) map area 357
29. **Dan Bragg and Glenn Norman** Aggregate potential of bedrock on the Avalon Peninsula 367
30. **F.T. Kirby** Detailed aggregate-resource assessments—insular Newfoundland 373
31. **M.J. Ricketts** Aggregates for export 379

GEOCHEMISTRY / GEOPHYSICS

32. **James Butler** Detailed lake sediment surveys for gold and associated elements in western Labrador 389
33. **John W. McConnell and Lisa A. Newman** Surficial geochemical surveys of auriferous portions of the Ashuanipi complex, western Labrador 397
34. **P.H. Davenport** The use of multi-element neutron-activation analysis of organic lake sediment in geochemical exploration for gold 403
35. **Gerry Kilfoil** Geophysical investigations at Weir's Pond, Mount Sylvester and Snowshoe Pond, Newfoundland: implications for lithologic distribution and structure 415

GENERAL PROJECTS

36. **A. Harris** Drill-core reduction—a pilot study 437
37. **A. Harris and S. Cochrane** Core-storage program, 1987 447
38. **C.F. O'Driscoll, J. Smith and G. Stapleton** Mineral Occurrence Data System 453
39. **Catherine Patey** Geoscan—the national database for geological information 456
40. **N.L. Mercer** Mineral Assessment Report Library—microfiche project 457

GEOLOGICAL SURVEY OF CANADA ABSTRACTS

41. **D.H.C. Wilton, C.S. MacDougall, L.M. MacKenzie and C. Pumphrey** Stratigraphic and metallogenic relationships along the unconformity between Archean granite basement and the early Proterozoic Moran Lake Group, central Labrador 458
42. **Derek H.C. Wilton** Copper occurrences in the Bruce River Group, Central Mineral Belt of Labrador 459
43. **Leonard M. MacKenzie and Derek H.C. Wilton** The Grenville Province boundary in the Burnt Lake area, Central Mineral Belt of Labrador 460
44. **Craig S. MacDougall and Derek H.C. Wilton** Geology of radioactive zones in the Round Pond area, Labrador 461
45. **Jon W. North and Derek H.C. Wilton** Stratigraphy of the Warren Creek Formation, Moran Lake Group, Central Mineral Belt of Labrador 462

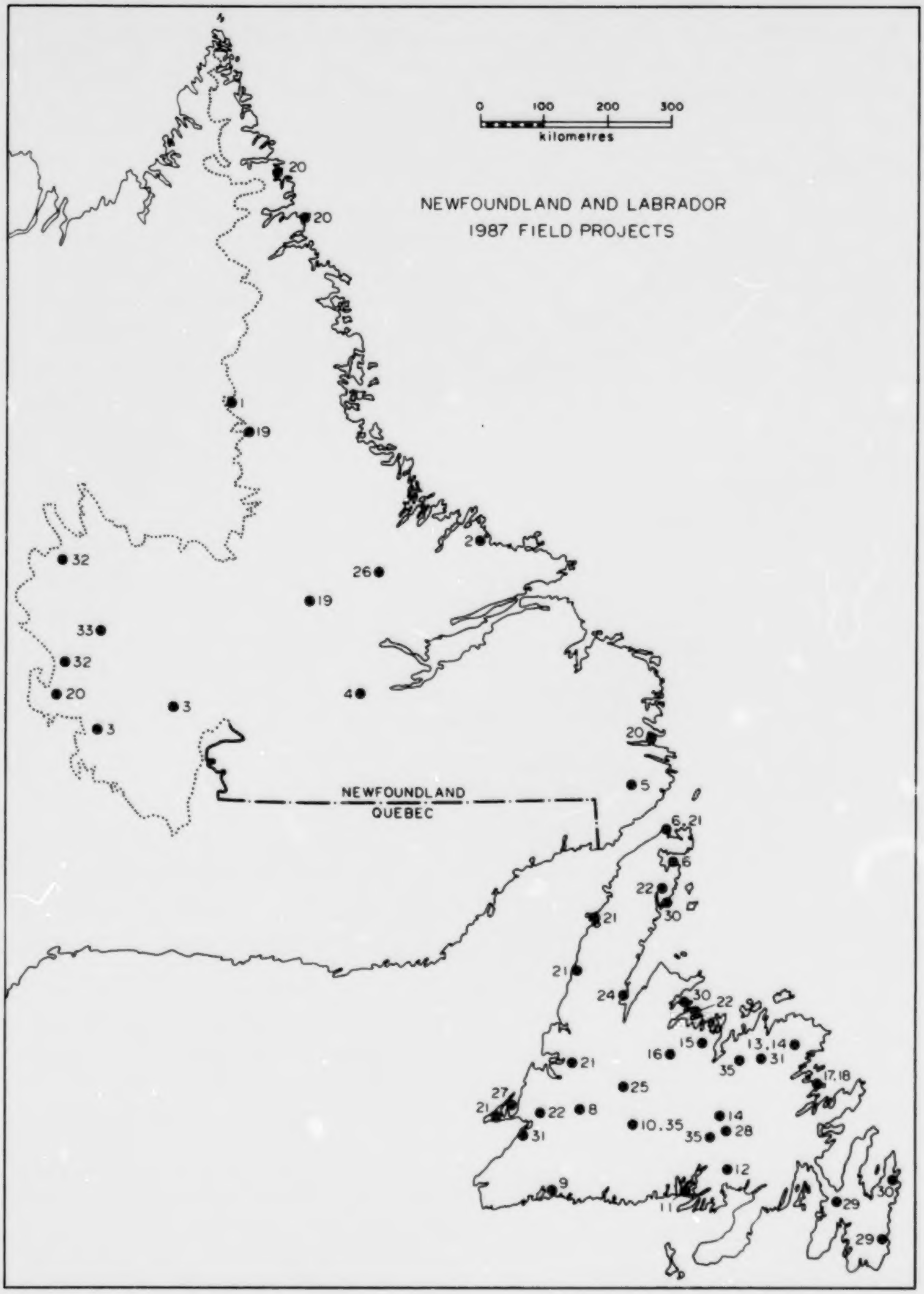
46. **Jeroen van Gool, Dennis Brown, Tom Calon and Toby Rivers** The Grenville Front thrust belt in western Labrador 463

47. **R.D. Klassen and F.J. Thompson** Glacial studies in Labrador 464

48. **D. Fox and J.T. Van Berkel** Mafic–ultramafic occurrences in metasedimentary rocks of southwestern Newfounland 465

49. **Z.A. Szybinski** New interpretation of the structural and stratigraphic setting of the Cutwell Group, Notre Dame Bay, Newfoundland 466

50. **H. Scott Swinden** Re-examination of the Frozen Ocean Group: juxtaposed middle Ordovician and Silurian volcanic sequences in central Newfoundland 467



NEWFOUNDLAND AND LABRADOR
1987 FIELD PROJECTS

0
100
200
300
kilometres
20
20
1
19
2
32
26
19
33
32
20
3
4
3
20
5
NEWFOUNDLAND
QUEBEC
6,21
6
22
30
21
21
24
30
22
15
16
13,14
35
31
21
17,18
25
27
21
22
8
14
10,35
35
28
31
12
9
11
30
29
29

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 1-14

THE DISCOVERY OF PROBABLE ARCHEAN ROCKS WITHIN THE LABRADOR ARM OF THE TRANS-HUDSON OROGEN NEAR THE LABRADOR–QUEBEC BORDER (NTS 14D/3,4,5 and 24A/1,8)

B. Ryan, D. Lee[1] and D. Dunphy[1]
Labrador Mapping Section

ABSTRACT

Migmatite gneiss and leucogabbro–anorthosite, intruded by deformed basic dykes, constitute a significant proportion of the lower Proterozoic Trans-Hudson terrane near the Labrador–Quebec border. The predyke rocks are considered to be remnants of Archean crust, and the dykes are correlated with a lower Proterozoic swarm in the North Atlantic craton. Most other gneisses in the area are apparently devoid of the dykes, and may be Proterozoic in age. Following intrusion of the dykes, there was granulite-facies metamorphism and development in much of the area of an intense, north-northwest-trending L–S fabric during Hudsonian thermotectonism. Sheets of late-kinematic biotite granite, a posttectonic dyke of olivine gabbro, and quartz monzonite and peralkaline granite plutons intrude the gneisses of the area.

INTRODUCTION

The Trans-Hudson Orogen represents the largest remnant of an eroded mountain chain in the Canadian Shield (Figure 1). During the past two decades a concentrated effort in the northwestern Trans-Hudson Orogen has been successful in constructing scenarios depicting the evolution of the belt (Lewry, 1987), and this history has been tentatively extended to its northern and easternmost parts (Hoffman, *in press*). Over the past few years several mapping projects in Labrador have begun to examine the evolution of the southeastern arm or 'Labrador segment' of the orogen (Figures 1 and 2) in an attempt to compare and contrast it with the history of the orogen established elsewhere.

The solutions to many of the problems that are apparent within the Trans-Hudson Orogen in Labrador are hampered by the lack of reliable geochronological data. It is thus difficult to ascertain the relative ages of the various zones or subdivisions identified in the orogen (cf. Korstgaard *et al.*, 1987; Wardle *et al.*, 1987, *in press;* Figure 2) and, consequently, to discuss the evolution of the orogen in terms of tectonic elements identified in younger mountain belts (cf. Monger *et al.*, 1972; Williams and Hatcher, 1983; Searle, 1983).

The lack of a firm geochronological foundation has necessitated reliance on lithostratigraphic correlation, a subjective technique that relies on perceived lithological similarities and structural–lithological sequences between areas that may be separated by tens or hundreds of kilometres. Lithostratigraphic correlation in the deeply eroded cores of orogenic belts is also risky because such terranes are remarkably similar, regardless of age. However, certain unique rock associations, with an apparent age restriction to their development, may provide a key to regional correlations in such belts. One such association is the layered leucogabbro–anorthosite complexes of the mid-Archean, a distinctive suite of rocks widely distributed throughout the North Atlantic Craton (Windley, 1973; Myers, 1981). The best known of these complexes is the Fiskenaesset Complex of West Greenland (cf. Myers, 1985), but many others occur worldwide in Archean cratons; e.g., the Sittampundi Complex of India (Ramadurai *et al.*, 1975), and the Nelson River anorthosites of Manitoba (Ermanovics and Davidson, 1976; Bell, 1978). Labrador also has similar Archean layered gabbro–anorthosite complexes: the Okakh Anorthosite and Tessiuyakh Gabbro complexes (Wiener, 1981), the Nachvak Fiord–Ryan's Bay anorthosites and gabbros (Wardle, 1983), and other unnamed bodies near Nain (Hurst *et al.*, 1973; Ryan and Lee, 1986) and Hopedale (Ermanovics *et al.*, 1982; Ryan *et al.*, 1983).

During the 1987 field season, we discovered several dismembered belts of 'Fiskenaesset-type' leucogabbro and anorthosite within gneisses in the Labrador–Quebec border area of the Trans-Hudson Orogen. These layered bodies have, however, been severely metamorphosed and migmatized such that few primary mesoscopic layering variations are preserved. In field aspect, they are virtually identical to Archean leucogabbro–anorthosite bodies north of Hopedale described and illustrated by Ermanovics *et al.* (1982, pages 158-159).

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

[1] Department of Earth Sciences, Memorial University, St. John's, Newfoundland, A1B 3X5

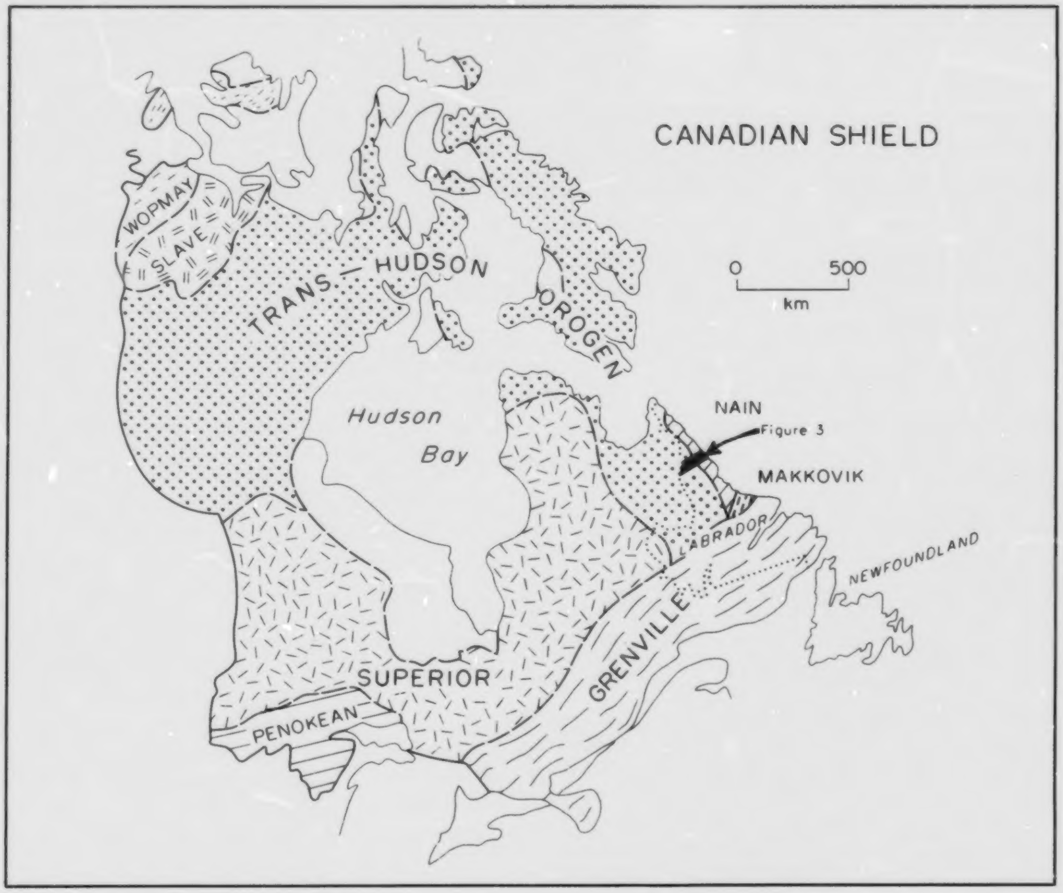


Figure 1. *Sketch map of the Canadian Shield showing the extent of the Trans-Hudson Orogen in relation to other components of the Shield. The Superior, Nain and Slave blocks are Archean, the Wopmay, Penokean, Makkovik and Trans-Hudson are Early Proterozoic, and the Grenville is late Middle Proterozoic.*

The presence of such leucogabbros and anorthosites within the lower Proterozoic Nagssutoqidian and Rinkian mobile belts of Greenland has been one of the lithological criteria used to demonstrate (Nunes *et al.*, 1974; Andersen and Pulvertaft, 1986) or suggest (Pulvertaft, 1973, page 537; Escher and Pulvertaft, 1976; Escher *et al.*, 1976) the presence of reworked Archean rocks within these belts. A similar argument, supported with other evidence, will be presented below.

PREVIOUS WORK AND REGIONAL FRAMEWORK

The interior of the Trans-Hudson Orogen in Labrador and eastern Quebec (Figure 1) is a complex comprising chiefly amphibolite- to granulite-facies rocks, which in terms of their character, can best be described as constituting a regional migmatite terrane. Taylor (1979) was the first to wrestle with separating the orogen in this area into regionally continuous subdivisions; however, the scale of the mapping (1:250,000) was such that many complexities within parts of the region are not apparent from his maps. A tentative subdivision of the northern Labrador segment, delineating several discrete zones (Figure 2), was proposed by Korstgaard *et al.* (1987) and Wardle *et al.* (1987; *in press);* these subdivisions are an attempt to portray the probable origin of the components of the segment in terms of their tectonic history.

The senior author began a 1:100,000-scale transect across the Trans-Hudson Orogen from the Archean Nain Province (or Nain craton) in the vicinity of Voisey Bay on the Labrador coast westward to the Quebec border in 1985. This project was designed to map the Archean–Proterozoic boundary zone across central Labrador, and to survey for mineralized peralkaline granitoid rocks among the Helikian felsic intrusions (Figure 3). Over this same time period Quebec provincial geologists were mapping eastward from the Labrador Trough to the Quebec–Labrador border (van der Leeden *et al.*, 1987). These two surveys have led to an improved understanding of the components that comprise the southeastern arm of the Trans-Hudson Orogen, and will eventually provide a complete cross-section of this part of the orogen, from the Superior Province bounding it in the west, to the Nain Province in the east (Figure 1).

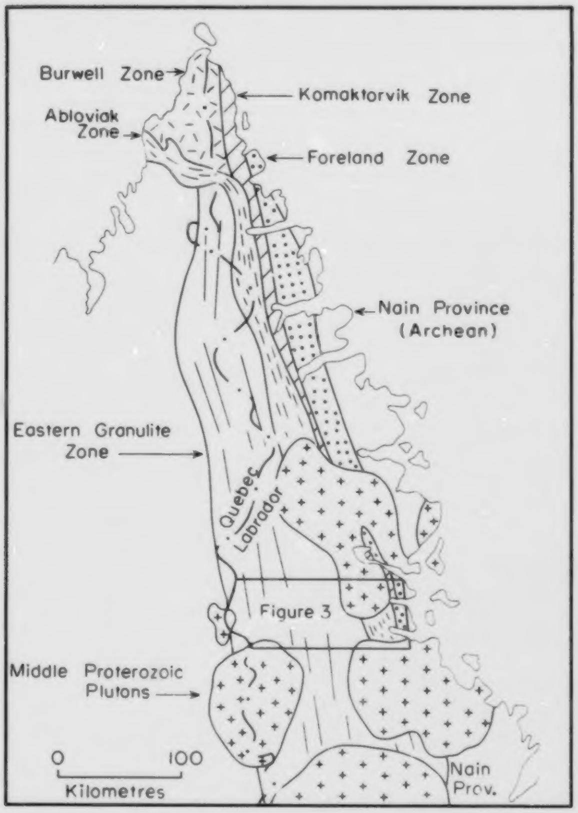


Figure 2. *Tectonic subdivisions of the Trans-Hudson Orogen in Labrador (modified after Wardle* et al., *in press).*

From the survey of the Trans-Hudson Orogen in central Labrador to date (Figure 3; Ryan and Lee, 1986; Ryan *et al.*, 1987), it has been shown that the easternmost part of the mobile belt in the Makavinekh Lake area comprises a 30-km-wide zone of garnet (± sillimanite ± biotite)–quartz–feldspar gneiss. This gneiss is a direct continuation of the Tasiyuak gneiss, a mylonitic, granulite facies diatexite with remnants of paragneiss, which can be traced for 450 km northwards to Ungava Bay, and which constitutes the Abloviak shear zone (Korstgaard *et al.*, 1987; Figure 2). This unit is in fault contact with Archean Nain Province gneisses to the east. It is succeeded westward in the Cabot Lake–Konrad Brook area by granulite- and amphibolite-facies orthogneisses containing numerous intercalated belts of metavolcanic and metasedimentary gneisses. The latter comprise a significant amount of metamorphosed calcareous rocks, metapelitic gneisses, and quartzite of presumed Early Proterozoic (Aphebian) age. One of the granulite-facies metaplutonic units in the northeast corner of the map corridor (Figure 3) has yielded a U–Pb age of 1909 $^{+33}_{-21}$ Ma (Krogh and Scharer, 1987), but it is unclear if this is the magmatic or metamorphic age (or both) of the zircon extracted from it. Although there may be pre-Aphebian rocks in the Trans-Hudson Orogen of the Makavinekh Lake–Cabot Lake area, we have little indication of this, and in fact most of the metaplutonic gneisses intrude and fragment the supracrustals. Unfortunately there are no other geochronological data for this area and we are still unsure of the age of many of the supracrustal rocks. Most are garnet–biotite–sillimanite–graphite gneisses, common in both the Archean and Proterozoic terranes of Labrador. Our only criterion for proposing that some are Aphebian is the preponderence of marble and quartzite, thus making them akin to the shelf sequences that bound the orogen (cf. Wardle and Bailey, 1981). Such belts are not characteristic of Archean terranes, but a recent study by Doig (1987) on the Ungava Peninsula has shown that some paragneiss belts containing pure quartzite and marble in the Trans-Hudson Orogen in that area are Archean. Therefore, it may be necessary to re-evaluate the Labrador occurrences in light of this evidence.

Injected into the layered gneisses are sheets of pink and white granitic pegmatite and medium- to fine-grained pink granite that carry only weakly developed simple planar and linear elements. These are late kinematic with respect to the formation of the gneissic layering. Two of these units are undergoing geochronological study by M.E. Bickford at the University of Kansas.

In the area of 'Moonbase' Lake, there is a discrete, north-northwest trending, granulite-facies, high-strain zone characterized by mylonitic, laminar-banded gneisses (Figure 3). Similar mylonitic gneisses, with foliated pink granitoid sheets, occur in the vicinity of the Mistastin River, but here the rocks are at amphibolite facies. The 1987 project was primarily concerned with rocks west of these (the same ?) mylonite zones.

MAJOR GEOLOGICAL SUBDIVISIONS OF THE LABRADOR–QUEBEC BORDER MAP AREA

The rocks of the 1987 project area (NTS 14D/3,4,5 and parts of 24A/1 and 8; Figure 4) can be conveniently broken down into three categories:

1) a suite of migmatitic gneisses and leucogabbro–anorthosite intruded by deformed and metamorphosed basic dykes;

2) a suite of gneisses with no unequivocal indication of metamorphosed dykes; these include supracrustal rocks, biotite- and pyroxene-rich gneisses, several granitoid gneisses, and foliated granite; and

3) basic and felsic posttectonic intrusive rocks.

Rocks Intruded by Deformed Basic Dykes

Granulite- and amphibolite-facies quartzofeldspathic migmatite containing intercalated units of gabbro–anorthosite comprise most of the area between 'Esker' Lake and the southeastern part of the project area. A funnel-shaped, foliated tonalite to tonalitic gneiss outcrops in the northeast corner of the 14D/3 map area; this may be younger than the enclosing migmatite. All these rock units are intruded by

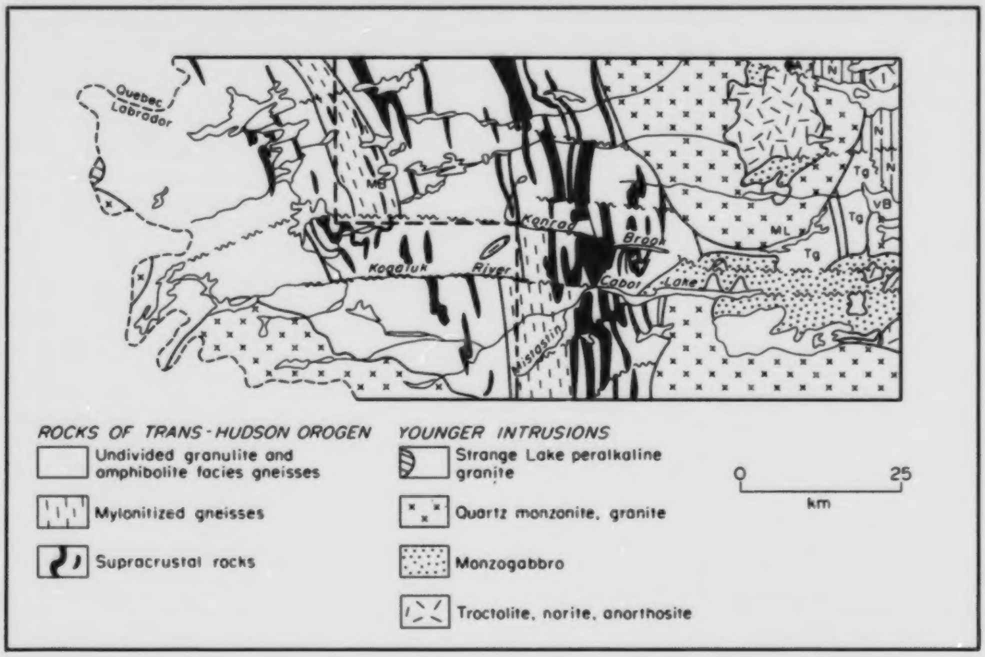

Quebec
Labrador
MB
Konrad
Brook
Kogaluk
River
Cabot
Lake
Mistastin
N
Tg
VB
ML
A
ROCKS OF TRANS-HUDSON OROGEN
Undivided granulite and amphibolite facies gneisses
Mylonitized gneisses
Supracrustal rocks
YOUNGER INTRUSIONS
Strange Lake peralkaline granite
Quartz monzonite, granite
Monzogabbro
Troctolite, norite, anorthosite
0
25
km

Figure 3. *Generalized geology of the Labrador transect of the Trans-Hudson Orogen examined between 1985 and 1987. Tg=Tasiyuak gneiss; N=Archean gneisses of the Nain Province, VB=Voisey Bay; ML=Makavinekh Lake; MB='Moonbase' Lake. A=location of dated sample referred to in text. The area west of the dashed line is the area mapped in 1987 and shown in more detail in Figure 4.*

variably deformed and metamorphosed basic dykes; the best preserved discordant dykes occur in the area between Long Pond and the Kogaluk River Fault.

The migmatitic gneisses (subunit 1a and 1g) throughout the area are grey-weathering (amphibolite facies) to buff- and yellow-brown-weathering (granulite facies) quartzofeldspathic rocks containing a fabric that varies from a diffuse layering to an anastomosing mylonitic foliation (Plate 1). In some places, the gneisses display a streaky, narrow, grey and white or grey and pink colour banding. This banding results from the deformation of an original biotite (+hornblende± orthopyroxene) granodiorite host that had been transected by a criss-crossing network of more potassic granitic veins and dykes. The more leucocratic network, lenses and bands contain well-developed mafic porphyroblasts, which give an indication of the degree of metamorphism; brown hypersthene at granulite facies and black hornblende at amphibolite facies. The latter is a retrogressive replacement of orthopyroxene. Numerous bands of amphibolite–mafic granulite, are intercalated with the quartzofeldspathic gneisses. In many cases, these bands are undoubtably deformed dykes since they truncate or lack the vein network of the surrounding quartzofeldspathic rocks. However, in other areas, the whole felsic–mafic gneiss assemblage is transected by a variety of younger, subconcordant sheets and veins of granite *(sensu lato)*.

The metamorphosed leucogabbro–anorthosite units (shown by small circle pattern on Figure 4) are a varied suite,

Plate 1. *Granulite-facies gneiss north of Kogaluk River. Note the large orthopyroxene crystal in felsic welt to the right of the lens cap (upper left). Rocks here have a mylonitic foliation. Mafic granulite (mg) layer on right side of photo may be deformed and metamorphosed dyke.*

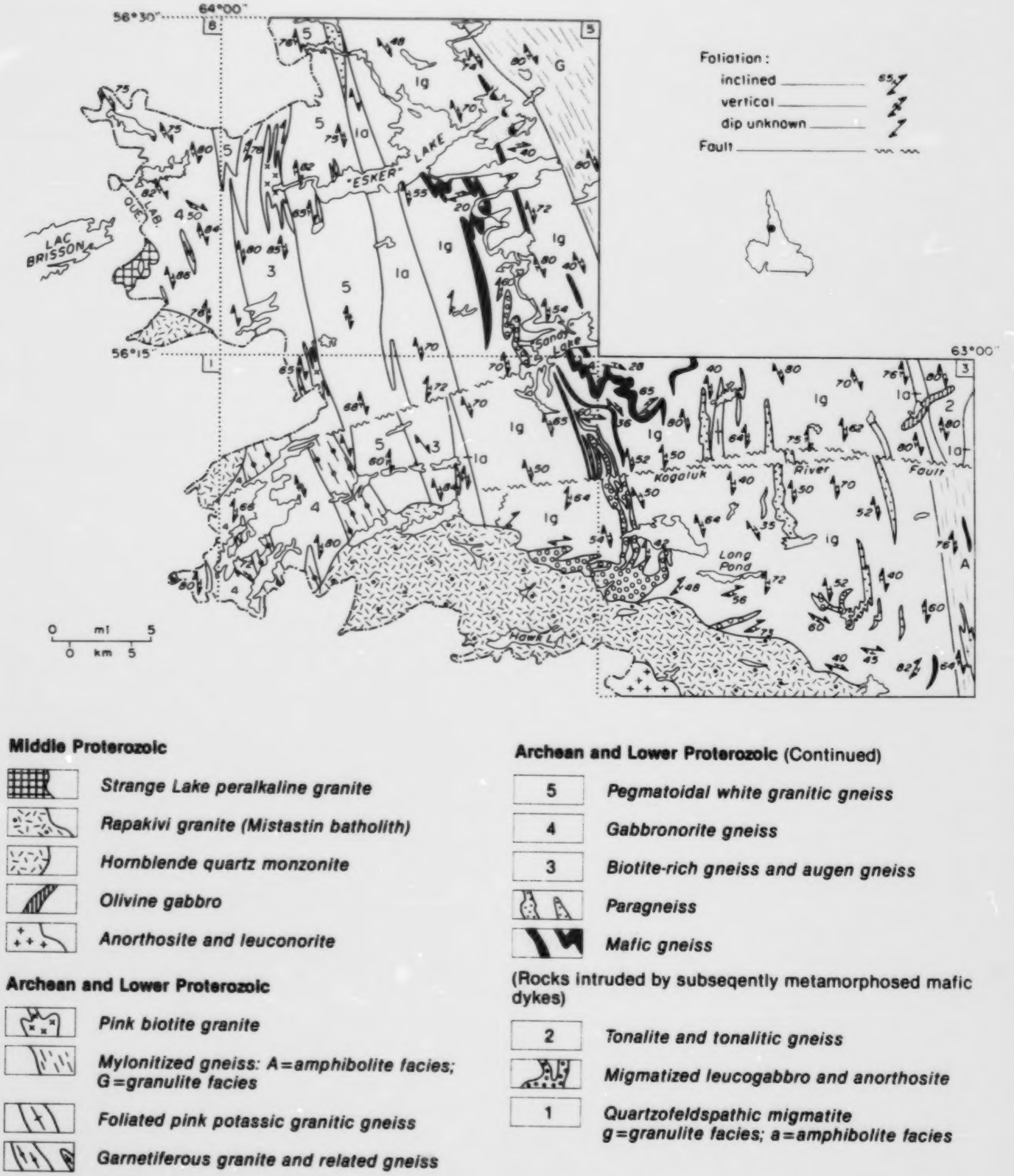

56°30'
64°00'
56°15'
63°00'
8
5
1
3
LAC BRISSON
QUE.
LAB.
"ESKER" LAKE
Sona Lake
Kogaluk River Fault
Long Pond
Hawk L.
lg
la
G
A
0 mi 5
0 km 5
Foliation:
inclined
vertical
dip unknown
Fault
Middle Proterozoic
Strange Lake peralkaline granite
Rapakivi granite (Mistastin batholith)
Hornblende quartz monzonite
Olivine gabbro
Anorthosite and leuconorite
Archean and Lower Proterozoic
Pink biotite granite
Mylonitized gneiss: A=amphibolite facies; G=granulite facies
Foliated pink potassic granitic gneiss
Garnetiferous granite and related gneiss
Archean and Lower Proterozoic (Continued)
5 Pegmatoidal white granitic gneiss
4 Gabbronorite gneiss
3 Biotite-rich gneiss and augen gneiss
Paragneiss
Mafic gneiss
(Rocks intruded by subseqently metamorphosed mafic dykes)
2 Tonalite and tonalitic gneiss
Migmatized leucogabbro and anorthosite
1 Quartzofeldspathic migmatite g=granulite facies; a=amphibolite facies

Figure 4. *Generalized geological map of the interior of the Trans-Hudson Orogen near the Labrador–Quebec border. Much of the area south of "Esker" Lake and east of Long Pond is covered by a thick veneer of glacial debris; the extent of map units in these areas is extrapolated or interpreted from aeromagnetic data (Geological Survey of Canada, 1983). The outline of the poorly exposed Strange Lake peralkaline granite is taken from an unpubished map by R. Miller and from Miller (1986). Numbers in boxes denote NTS 1:50,000 scale map sheets 14D/3,4,5 and 24A/1,8.*

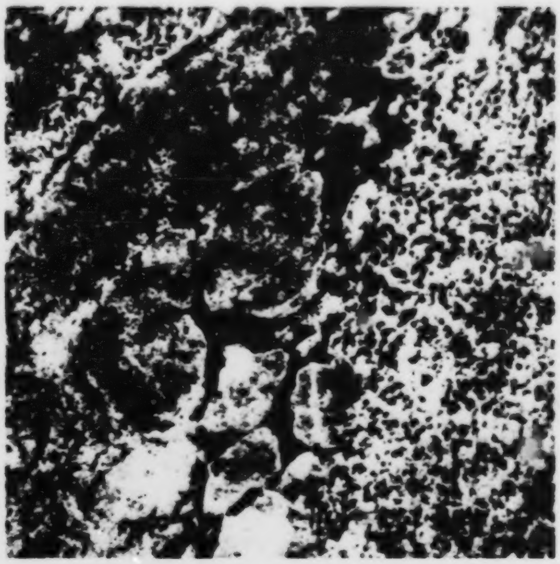


Plate 2. *Snowball-textured gabbro, injected by granitic material exhibiting granulite facies mineralogy, west of Long Pond. Largest plagioclase "ball" is 10 cm in maximum dimension.*

ranging from pure white, granular, quartz-bearing anorthosite, to streaky hornblende-bearing anorthosite and leucogabbro. A very distinctive morphological type among the leucogabbros and gabbros is a 'snowball' or 'tennis-ball' texture, in which white, ovoidal, plagioclase up to 15 cm in diameter is surrounded by a black, hornblende-rich matrix (Plate 2). Fragments of such leucogabbroic–anorthositic rocks occur widely distributed within the quartzofeldspathic gneisses, and are not shown on Figure 4. In fact, the gabbro–anorthosite units that are shown on the map are not all coherent monolithologic bodies, but in many cases are zones in which the amount of gabbro–anorthosite relative to the younger quartzofeldspathic gneisses varies from 20 to 90 percent; only one unit of fairly massive metaigneous rocks of this type has been delineated (about 3 km south of Long Pond).

Tonalite and tonalitic gneiss (Unit 2) is a distinctive unit in the northeast corner of map area 14D/3. It is a pale- to dark-grey-weathering, hornblende- and biotite-bearing rock, which locally displays only a slight fabric. Textural features, which locally characterize the unit, are remnant dark grey, primary (igneous), plagioclase and clots of black hornblende; these stand out especially in the lighter-weathering areas. It locally contains a predeformational vein network similar to that described above for parts of the migmatite complex.

All of the rock units mentioned above are either plainly intruded by variably deformed and metamorphosed basic dykes or contain layer parallel units of amphibolite–mafic granulite that can be interpreted as having been derived from such dykes. The best examples of the relationship between the dykes and other rocks can be seen in the granulite-facies terrane of the Long Pond–'Sandy' Lake area, where numerous dykes occur. These dykes vary from a few centimetres to 25 m in width and are largely recrystallized, usually exhibiting granulite-facies mineralogy (i.e., hypersthene–diopside–hornblende–plagioclase). Not all dykes are massive and undeformed; most are folded, lineated and foliated on their margins, and in zones of high strain are concordant to gneissosity, attenuated and/or boudinaged and carry a pronounced planar fabric. Unlike the gneisses they intrude, and older fragmented mafic units within them, the dykes are not migmatized (Plate 3). The only veining noted in the dykes consists of irregular, synmetamorphic, hypersthene-bearing 'sweats' and late-kinematic granitic pegmatites with a weak or nonexistant foliation. Where best preserved, the dykes exhibit relict primary subophitic and locally porphyritic textures. Large phenocrysts of blue labradorite feldspar have been noted in several dykes, but this is uncommon; typically, the feldspar 'phenocryst' is a white polycrystalline aggregate that is elongate where the dykes are deformed.

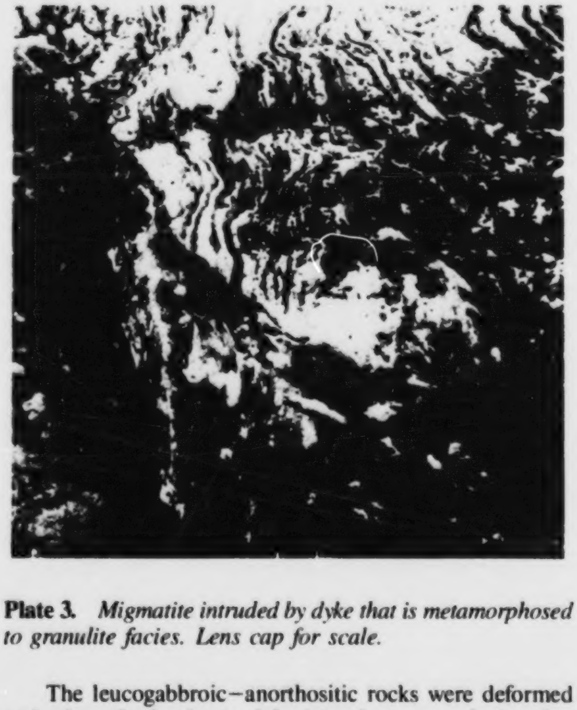


Plate 3. *Migmatite intruded by dyke that is metamorphosed to granulite facies. Lens cap for scale.*

The leucogabbroic–anorthositic rocks were deformed and migmatized prior to dyke intrusion, a conclusion that arises from (1) the observation of randomly oriented, foliated, leucogabbroic fragments within a granitic host containing a more singularly oriented fabric, both of which are truncated by the metamorphosed dykes, and (2) that of areas of foliated leucogabbro intruded by highly discordant, nonfoliated, recrystallized dykes.

Rocks Generally Without Unequivocal Metamorphosed Dykes.

Most of the other gneisses in the map area generally lack convincing evidence of having been intruded by mafic dykes. The presence of metamorphosed and deformed dykes cannot be entirely ruled out since narrow homogeneous mafic units do occur in these gneisses. Usually, these mafic bands exhibit the same neosome network as their hosts. We have, however, observed two outcrops of migmatized mafic gneisses that are crosscut by nonmigmatized metamorphosed dykes (see below). Gneisses that fall into this category range in composition from migmatitic supracrustal and granitic orthogneisses to a deformed, two-pyroxene, basic pluton.

Mafic gneisses, presumed to be largely of supracrustal origin (shown as solid black on Figure 4) and metasedimentary rocks (shown as closely spaced dotted pattern on Figure 4) occur throughout the area. The mafic gneisses range from less than a metre in length and width to several hundred metres in width and several kilometres in length. They show varying degrees of migmatiztion by younger granitoid veins and dykes; some of these younger granitoids clearly emanate from the surrounding quartzofeldspathic gneisses. The mafic units are generally clinopyroxene–amphibolite and hornblende-rich mafic granulite in which the layering is defined by variations in colour index. Locally, these mafic units are characterized by almandine garnet, which may occur as clusters up to several centimetres in diameter. Coronal overgrowths or complete pseudomorphs of symplectic plagioclase and hornblende have been observed after garnet in some mafic granulites, a reaction attributed to hydration following granulite-facies metamorphism (cf. Wells, 1979). We have observed two outcrops in which a metamorphosed mafic dyke crosscuts these migmatized mafic units; such relationships suggest that perhaps many, if not all, of these mafic gneisses may predate dyke emplacement.

Also interlayered with the quartzofeldspathic gneisses are units of migmatized garnet–sillimanite–biotite paragneiss, white sillimanite–muscovite quartzite and rare garnet–clinopyroxene–quartz rock. Dark-grey to brown, impure marble and clinopyroxene-rich calc-silicate rock also occur locally as inclusions; these are rare and are generally less than 10 m in width and less than 100 m in length. The problem of assigning an absolute or relative age to these paragneisses has been noted earlier; even though they are migmatized, they do not appear to be intruded by the metamorphosed dykes.

Dark-grey-weathering, biotite- and hornblende-rich quartzofeldspathic gneiss and intercalated mafic gneiss (Unit 3), characterized by pinch-and-swell, *lit-par-lit,* medium grained to pegmatoidal granitoid layers of at least three generations, outcrops west of 'Esker' Lake and southwest of 'Sandy' Lake (Plate 4). The internal mineral fabric in this gneiss is well developed because of the abundance of biotite, but in some areas there are elongate streaks of granular feldspar and discrete feldspar augen that suggest derivation, in part, from an originally porphyritic granitoid protolith.

Plate 4. *Biotite–hornblende migmatite gneiss south of 'Esker' Lake. Pinch-and-swell structure of leucosome is not uncommon in this unit.*

This migmatite unit is bounded to the west in the 'Esker' Lake–Lac Brisson area by a massive to gneissic unit varying from melagabbronorite to quartz-bearing gabbronorite and garnetiferous leuconorite (Unit 4). Though mostly a granulite-facies rock, it was locally retrogressed under amphibolite-facies conditions (giving rise to quartz diorite gneiss and leucoamphibolite), especially within the contact aureoles of younger felsic plutons south of Lac Brisson. The mesoscopic texture of the unit varies from fine- to medium-grained, massive, equigranular (with 'salt and pepper' appearance), to coarsely porphyritic (augen texture where highly deformed) and coarse grained gabbroic displaying relict subophitic textures (Plate 5). The finer grained, melacratic portions are identical in their field appearance and mineralogy to the metamorphosed basic dykes described previously, suggesting that this unit may have been the deeper plutonic feeder to the dykes. This metaplutonic unit is intruded by numerous sheets of white to pink, garnetiferous granite and its gneissic equivalents in the southwest corner of the map area (Figure 4), and gives rise to a mixed, migmatitic, unit. The gabbronorite is variably affected by Hudsonian deformation. In many areas, there is no obvious planar fabric but a linear one is present. In other areas, a planar fabric is detected only in narrow felsic crosscutting veins. Yet, in other areas, the unit has a well-developed augen texture, a gneissic layering, or it shows indications of polydeformation. We attribute the variety of features to primary heterogeneities within the intrusion and its inhomogeneous response to subsequent deformation.

A very distinctive white-weathering granitoid gneiss (Unit 5) trends north-northwest through the western part of 'Esker' Lake. This unit is medium grained to pegmatoidal.

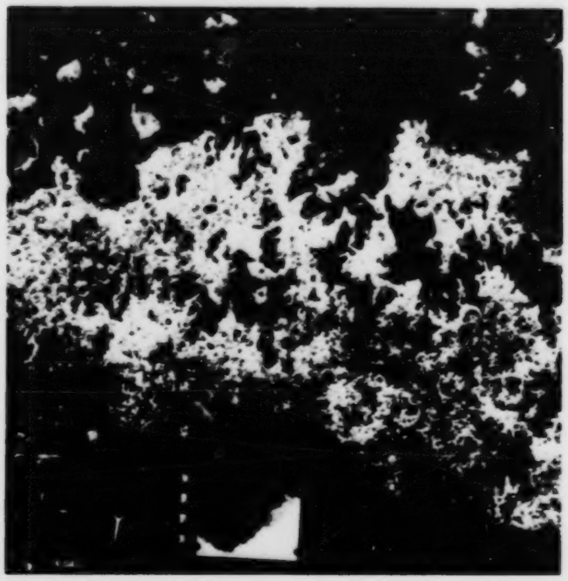


Plate 5. *Primary igneous texture in a coarse grained, mildly recrystallized part of the gabbronorite gneiss unit east of Lac Brisson. Such preservation of primary features is rare.*

In places, it lacks a well-defined layering, but generally it exhibits a schlieric foliation defined by discontinuous subparallel seams of biotite. It contains numerous screens of older gneiss, especially the migmatite of Unit 3. This unit is poorly exposed, except northwest of 'Esker' Lake. It is noteworthy for its local zones of radioactivity, a feature that makes it readily identifiable on airborne gamma-ray spectrometer maps of the area (Geological Survey of Canada, 1986). It is manifested in an aeromagnetic low (Geological Survey of Canada, 1983), which we have used to interpret its distribution in the drift-covered parts of map areas 14D/4 and 14D/5. This unit displays an intense mylonitic fabric in exposures along a string of small lakes at its southern end. This reflects an increase in the deformation from north to south.

Variably foliated biotite–garnet granite gneiss forms a poorly exposed unit in the southwest corner of the map area and occurs as a migmatizing agent within Unit 4. Sheets of foliated garnet granite believed to be related to this unit also locally crosscut the gneisses of Unit 5. The gneiss ranges from an equigranular white, leucocratic, garnetiferous granitoid rock (similar to the mylonitic diatexites of the Abloviak shear zone near Voisey Bay referred to earlier) to a porphyritic medium grained, pink- to grey-weathering rock containing abundant pink feldspar augen, in which garnet is concentrated in the biotite-rich parts of the matrix.

Pink foliated potassic granite and related gneiss occur throughout the area as narrow sheets interlayered with the other rocks. They are no doubt of several generations, and only a few of the larger ones are shown (as crosses) on Figure 4. All such rocks are salmon pink in colour, vary texturally from aplitic to medium grained, and commonly exhibit a shiny glacial polish.

Massive to weakly foliated, white- to pink-weathering, equigranular, fine grained biotite granite (shown by x pattern on Figure 4) forms an elongate body interdigitating with gneisses of Unit 3 west of 'Esker' Lake and also near the Quebec border on 14D/3. The generally undeformed nature of these rocks led Taylor (1979) to interpret the northernmost body as a continuation of a quartz monzonite pluton that occurs to the south-southwest (see below). However, the texture of the granite and morphology of the contact between the granite and its country rocks differ from that of the quartz monzonite, and it is considered instead to be a late-kinematic Hudsonian intrusion.

Basic and Felsic Posttectonic Intrusions

A large dyke of undeformed olivine gabbro and three felsic plutons constitute intrusions that postdate the regional metamorphism and deformation of the surrounding gneisses. The gabbro dyke (shown by parallel cross-hatching on Figure 4) is a 5 by 1 km intrusion outcropping in the northeast corner of 14D/3. It is a coarse grained, leucocratic to melacratic rock in which plagioclase locally forms radiating clusters. It is considered to be contemporaneous with similar mafic rocks of the Nain Plutonic Suite in the Voisey Bay area (Ryan and Lee, 1986).

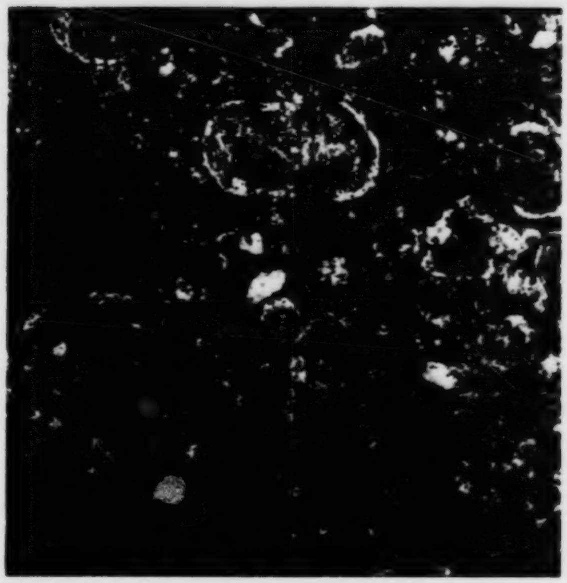


Plate 6. *Densely packed, mantled, ovoidal, feldspar megacrysts, typical of the Mistastin batholith.*

The most extensive felsic unit occurs along the southwest corner of the map area encompassing the northern part of the Mistastin batholith, a generally rusty-weathering rapakivi quartz monzonite to granite (Emslie *et al.*, 1980). It is characterized by abundant, ovoidal, mantled potassium feldspar megacrysts in a medium grained hornblende-bearing matrix (Plate 6). A large raft of anorthosite and leuconorite, with blue chatoyant feldspar, is enveloped by the granite batholith along the southern perimeter of the map area

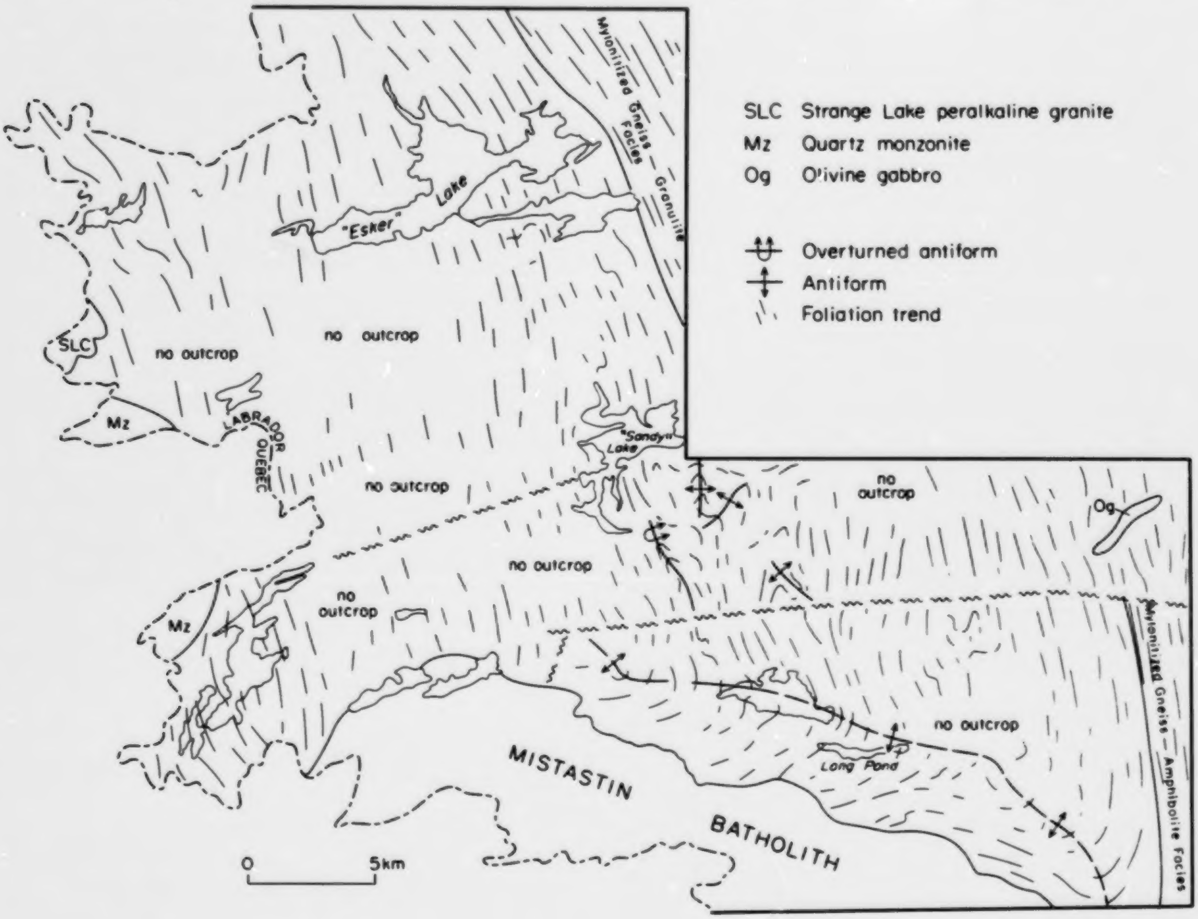

SLC Strange Lake peralkaline granite
Mz Quartz monzonite
Og Olivine gabbro
Overturned antiform
Antiform
Foliation trend
Mylonitized Gneiss Facies
Granulite
"Esker" Lake
SLC
no outcrop
Mz
LABRADOR
QUEBEC
"Sandy" Lake
Og
Mylonitized Gneiss — Amphibolite Facies
Long Pond
MISTASTIN
BATHOLITH
0
5km

Figure 5. *Generalized trend-line map for area shown in Figure 4. Note that this map does not differentiate foliations of differing ages.*

(Figure 4). The Mistastin batholith has a pyroxene- and hornblende-hornfels contact aureole up to 2 km wide. One of the most distinctive features of the aureole is the growth of large, randomly oriented, skeletal biotite porphyroblasts in the migmatitic gneissic matrix to the anorthosite unit west of Long Pond. It is worthy of note that foliations in the country-rock gneisses are oriented roughly parallel to the contact with the batholith southeast of Long Pond; however, this appears to be a pre-intrusion orientation (see below), since the trend is in fact truncated by the batholith on a regional scale (Figures 4 and 5). The continuity of country-rock aeromagnetic signatures into areas underlain by granite (Geological Survey of Canada, 1983) suggests that the Mistastin batholith in this area is a relatively thin subhorizontal sheet.

The westernmost pluton, composed of hypidiomorphic-textured, pink-weathering quartz monzonite forms scattered outcrops along the western periphyry of the area. It is distinguished from the Mistastin batholith by the lack of mantled, ovoid, feldspar megacrysts. Currie (1985) has noted such textures in the extension of this pluton west of the Labrador–Quebec border, but this has not been confirmed either by the writers or by Quebec geologists (e.g., Bélanger, 1984).

The Strange Lake Alkalic Complex (Currie, 1985; Miller, 1986) with its REE–zirconium–yttrium deposit, straddles the Labrador–Quebec border. It is drift-covered in the study area, and is exposed in only a few outcrops southeast of Lac Brisson, where it comprises a grey-weathering, 'spotted' riebekite granite. The spotted appearance is caused by conspicuous black riebekite crystals. The complex has been the subject of intense exploration and study since its discovery by the Iron Ore Company of Canada in 1979 (cf. Hlava and Krishnan, 1980; Miller, 1985, 1986; Currie, 1985). Radiometric dating of the complex has yielded a K–Ar age of 1271 ± 30 Ma (Currie, 1985) and a Rb–Sr age of 1189 ± 32 Ma (Duthou *et al.*, 1986).

Undeformed, fresh to slightly altered, rectilinear diabase dykes (not shown in Figure 4), varying from a few centimetres to tens of metres in width, are widely distributed within the gneissic terrane. Their absolute age is unknown, but in the eastern part of the project corridor near Makavinekh Lake (Ryan and Lee, 1986), they crosscut Helikian rapakivi plutons. This shows that they postdate the youngest plutonic activity associated with the Nain Plutonic Suite.

STRUCTURAL GEOLOGY AND METAMORPHISM

A cursory examination of the map patterns (Figure 4) indicates that the study area is dominated by a north-northwest-trending, generally steeply dipping assemblage of gneisses. Tight folds, defined and postulated on the basis of the distribution of a few marker units and the aeromagnetic patterns, have axial plane trends parallel to the overall gneissosity. Deviations, however, are apparent south of 'Sandy' Lake and in the area of Long Pond where units, folds and foliations trend roughly east-west. These variations, shown on a foliation trend map (Figure 5), indicate a history of multiple deformation, but the correlation of this history with regional tectonic events in the Trans-Hudsonian Orogen elsewhere in Labrador (cf. Korstgaard *et al.*, 1987; Wardle *et al., in press)* is not yet established. A few salient features of the deformation seen in this area are outlined below.

The generally north-northwest-trending gneissic layering, the gneissic foliation and the tight to isoclinal folds that dominate the map pattern are considered the chief manifestation of Hudsonian deformation. The gneissosity is usually steeply dipping, but is locally subhorizontal. Shallow dips are especially common south of 'Esker' Lake where numerous isoclinal folds, shallowly plunging to the north, are present. A prominent shallowly plunging mineral-rodding lineation (not shown on Figures 4 and 5) associated with the folds is also conspicuous in the 'Esker' Lake area. This lineation is the chief fabric orientation that can be detected in many horizontal exposures; only on appropriate subvertical outcrop surfaces can the gneissic layering attitude be seen. A subhorizontal lineation and shallowly plunging folds are also common in other parts of the area, but steeply plunging structures are present as well. In fact, mesoscopic structures with varying style and attitude can occur over small areas. The relationships between these mesoscopic fold structures are not yet understood.

As noted above, east-west-trending structures are present in the 'Sandy' Lake and Long Pond area. The former area appears to reflect the effects of superposed folding (Figure 5), a notion supported by the common occurrence of closed interference structures (Type 1 of Ramsay, 1967; Plate 7). The distribution of the leucogabbro–anorthosite units west of Long Pond also suggests elongate closed interference patterns, but these appear to be older than those of the 'Sandy' Lake area.

The gneissic foliation attitudes near Long Pond outline a large open antiform, plunging moderately to the southeast. The southern limb of this fold is truncated by the Mistastin batholith (Figure 5) so the antiform is not considered to be related to batholith intrusion, but to be an older structure in the gneiss terrane, possibly equivalent to similar open folds outlined by Taylor (1979) west of the batholith in Quebec.

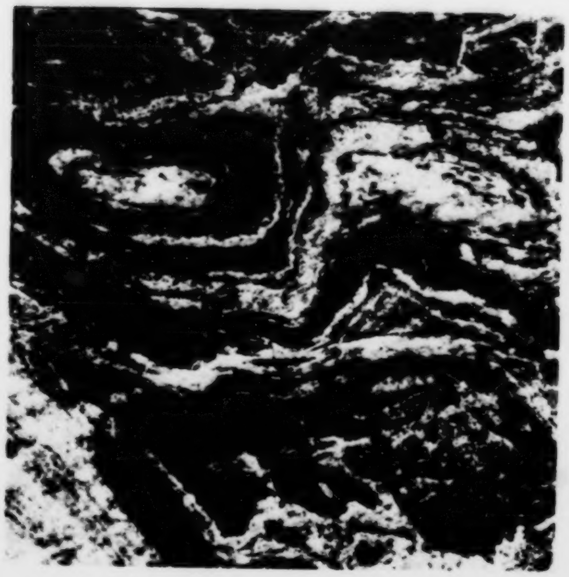


Plate 7. *Interference patterns in gneisses southeast of 'Sandy' Lake. Such structures are not uncommon in the 'Sandy' Lake–Long Pond sector of the area.*

Two extensive zones of mylonitized rocks occur in the area (Figures 4 and 5) together with more commonly occurring localized narrow mylonite zones. The southern mylonite zone comprises predominantly grey, hornblende-blastic, amphibolite-facies gneisses containing numerous intercalated pink granite sheets. An anastomosing foliation and prominent shallowly plunging mineral lineation characterize this zone. The granulite-facies northern zone also displays a shallowly plunging mineral-rodding lineation and related small-scale isoclinal folds within a steeply dipping, mylonitic, laminar, gneissic banding. The northern zone contains rocks that are plainly derived from the predyke terrane. The lineation in both these high-strain zones has the same character and orientation as that found in the Abloviak and Komaktorvik zones on the western margin of the orogen (Figure 2), implying an origin in a similar transcurrent shear regime (Korstgaard *et al.*, 1987; Wardle *et al.*, 1987; *in press).*

The metamorphic mineral assemblages in the gneisses reflect upper-amphibolite- and granulite-facies conditions as outlined in the previous sections. The amphibolite-facies rocks appear to be a result of retrogression from granulite facies since relict hypersthene is locally present in some parts of the lower-grade terrane. A 2-km-wide pyroxene- and hornblende-hornfels contact aureole around the Mistastin batholith is characterized by dark-brown, friable quartzofeldspathic gneisses, and metasedimentary gneisses in which garnet and sillimanite are replaced by hypersthene, cordierite and spinel. These features are identical to those observed around plutons in the Nain Plutonic Suite to the east (Ryan and Lee, 1986).

THE EVIDENCE FOR ARCHEAN ROCKS IN THE PROJECT AREA

The lack of a firm geochronological data base has been a major obstacle to deciphering the geological evolution of the Trans-Hudson Orogen in Labrador. Taylor (1979) considered that all of the rocks in this area were Early Proterozoic (Aphebian). Korstgaard *et al.* (1987) and Wardle *et al. (in press)*, on the other hand, have postulated that the interior gneisses probably comprise significant volumes of reworked Archean crust. It is proposed here that the Labrador–Quebec border area contains remnants of such older crust that have not been thoroughly structurally reconstituted during the Hudsonian Orogeny. The proposal is based on two main premises, viz. (1) that the leucogabbroic–anorthositic rocks of the map area are time equivalents of similar layered complexes in the Archean gneiss terranes of Labrador and Greenland, and (2) that the metamorphosed diabase dykes are the time equivalents of the lower Proterozoic (2300-2400 Ma) swarm intruded into the Archean Nain Province, and therefore all rocks intruded by such dykes in the present study area are also Archean.

It is not possible to fully define the extent of this predyke (Archean) gneiss terrane because throughout most of the area, any discordance between an earlier layering and the dykes has been destroyed by the high strain and transposition associated with Hudsonian deformation. However, where the gneiss–dyke assemblage appears to have been simply reoriented into a parallel layered complex, the veined character of the gneisses contrasts with the massive metamorphosed dykes. Unfortunately, Hudsonian migmatization has also affected most of these (transposed) gneisses so that the recognition of 'early' migmatite within such rocks is tenuous.

Although the trend of the gneisses in the 'Esker' Lake–Long Pond area is parallel to that of Hudsonian fabrics throughout the Trans-Hudson Orogen of this region, these gneisses appear to have preserved pre-Hudsonian features. These gneisses have been metamorphosed under granulite facies conditions during the Hudsonian Orogeny, but they have not been affected by the same intensity of structural overprint as other gneisses in this area. A sharp boundary between 'gneisses with discordant dykes' and 'gneisses with transposed dykes' cannot be easily drawn due to variations in strain intensity across the area, but the least amount of transposition is seen in the area south and west of Long Pond. This area also contains the 'older' elongate interference patterns (outlined by the leucogabbro–anorthosite units), perhaps an indication that the map pattern in this area (Figure 4) is a function of the reorientation of pre-Hudsonian (predyke?) gneissic structures by Hudsonian deformation. It is apparent in the field that the dykes crosscut mesoscopic (Archean?) fold structures in the gneisses (Plate 8), but insufficient data are available to unequivocally define any predyke macroscopic folds. Even in the area near Sandy Lake, where most dykes and their hosts have been transposed into parallelism, there are strain shadows adjacent to some of the thickest dykes in which the predyke migmatized and folded character of the complex can be seen.

Plate 8. *Mesoscopic open fold structure truncated by granulite-facies metamorphosed dyke south of Long Pond. Dark lens at top of photo is one of a number of older migmatized mafic pods in the gneiss at this locality. Field of view is 50 cm wide.*

Interestingly, the area in which the dykes have been recognized occurs west of major zones of mylonitized gneisses, suggesting that these zones may represent major structural junctions between the rocks of this area and those examined previously to the east. There are, however, isolated exposures in the Cabot Lake–'Moonbase' Lake area (Figure 3) in which nonmigmatized, massive amphibolite–mafic granulite units show slight discordance to layering of the enclosing quartzofeldspathic gneiss (Ryan *et al.*, 1987, page 157). In addition, there are isolated occurrences of snowball-textured metaleucogabbro and meta-anorthosite in the gneisses of the same area, one of which forms a mappable unit at 1:100,000 scale (Ryan *et al.*, *op. cit.*). The mylonite zones, therefore, do not seem to represent major junctions between crustal blocks with widely differing lithostratigraphic components. Instead, they are local high-strain zones within the same crustal block, which may in part bound regions with pre-Hudsonian features still preserved.

CONCLUSIONS

Leucogabbro–anorthosite complexes and migmatitic gneisses transected by metamorphosed diabase dykes have been discovered within the Trans-Hudson Orogen near the Labrador–Quebec border. It is proposed that the predyke complex represents Archean crustal components, which, in part, have escaped the greatest imprint of Hudsonian deformation, but which have been metamorphosed under the prevailing granulite-facies regional metamorphism. These Archean rocks may constitute either a westward extension of the Nain crust, which has escaped wholesale reworking, or an exotic terrane that has been incorporated into the

Trans-Hudson Orogen through accretion. If our conclusion, which is based on field relationships, is correct, then this represents the first concrete field evidence of Archean rocks within the Trans-Hudson Orogen of this region. Archean components have been identified by zircon dating within the southern Labrador sector of the Trans-Hudson Orogen near Churchill Falls (Krogh, 1986), and have been postulated elsewhere on the basis of Nd−Sm signatures from younger plutons (Ashwal *et al.*, 1986). In addition, there are radiometric indications of pre-Hudsonian crustal components in the Trans-Hudson terrane of Quebec west of the study area (van der Leeden, personal communication, 1987). The existence of preserved remnants of recognizable Archean crust in the interior of the Trans-Hudson Orogen in Labrador−Quebec, supports the contention of Korstgaard *et al.* (1987) that this region largely comprises a reworked Archean terrane with infolded and metamorphosed Aphebian cover. The extent of the Archean crust is not readily obvious because of the intensity of the Hudsonian overprint, and the paucity of radiometric ages. Dr. U. Scharer (at Université du Québec, Montréal) has recently begun a geochronological investigation of samples from several units in the predyke terrane of the map area in an attempt to test the hypothesis outlined above.

ACKNOWLEDGMENTS

We thank our assistants Terry Wiseman, Tilman Bieger, and Scott Biggin for their humor, hard work and intestinal fortitude in the face of a miserable field season on the Labrador plateau. Ron Grimes kept us well fed, and Normand Denis kept us supplied for the season due to the efforts of Ken O'Quinn, Richard White and Wayne Tuttle in Goose Bay. Universal Helicopters gave us their top pilots and engineers. Iron Ore Company of Canada graciously allowed us accommodation at their Lac Brisson cabins, a comfortable port in the storms of the worst summer in a dozen years. We thank R.J. Wardle and A.P. Nutman for thorough critical readings of an earlier version of this paper, and R. Miller for a field trip, discussions and access to his unpublished maps.

REFERENCES

Andersen, M.C. and Pulvertaft, T.C.R.
1986: Occurrences of anorthositic rocks in the reworked Archean basement in the Umanak central West Greenland. Gronlands Geologiske Undersogelse, Rapport 129, 12 pages.

Ashwal, L.D., Wooden, J.L. and Emslie, R.F.
1986: Sr, Nd and Pb isotopes in Proterozoic intrusives astride the Grenville Front in Labrador: Implications for crustal contamination and basement mapping. Geochimica et Cosmochimica Acta, Volume 50, pages 2571-2585.

Bélanger, M.
1984: Région du Lac Brisson; 1:50,000 scale map. Ministére de l'Energie et des Ressources, Gouvernement du Québec, Open File DP.84-20.

Bell, C.K.
1978: Geology, Wekusko Lake map area, Manitoba. Geological Survey of Canada, Memoir 384, 84 pages.

Currie, K.L.
1985: An unusual peralkaline granite near Lac Brisson, Quebec−Labrador. *In* Current Research, Part A. Geological Survey of Canada, Paper 85-1A, pages 73-80.

Doig, R.
1987: Rb-Sr geochronology and metamorphic history of Proterozoic to early Archean rocks north of the Cape Smith Fold Belt. Canadian Journal of Earth Sciences, Volume 24, pages 813-825.

Duthou, J.L., Pillet, D. and Chenevoy, M.
1986: Rb-Sr geochronology of the Lac Brisson peralkaline granite (Labrador, Northeast Canada) (abstract). International Geochemical and Cosmochemical Congress, Meeting, Cambridge, England.

Emslie, R.F., Cousens, B., Hamblin, C. and Bielecki, J.
1980: The Mistastin Batholith, Labrador−Quebec: an Elsonian composite rapakivi suite. *In* Current Research, Part A. Geological Survey of Canada, Paper 80-1, pages 95-100.

Ermanovics, I.F. and Davidson, W.L.
1976: The Pikwitonei granulites in relation to the northwestern Superior Province of the Canadian Shield. *In* The Early History of the Earth. *Edited by* B.F. Windley. John Wiley and Sons, London, pages 331-347.

Ermanovics, I., Korstgaard, J. and Bridgwater, D.
1982: Structural and lithological chronology of the Archean Hopedale Block and adjacent Proterozoic Makkovik Subprovince, Labrador: Report 4. *In* Current Research, Part B. Geological Survey of Canada, Paper 82-1B, pages 153-165.

Geological Survey of Canada
1983: Tasisuak Lake, Newfoundland−Quebec, 1:250,000 aeromagnetic map. Geological Survey of Canada, Map 7436G.

1986: Gamma ray spectrometry, Tasisuak Lake, Labrador−Quebec. Geological Survey of Canada, Map 35001G.

Escher, A. and Pulvertaft, T.C.R.
1976: Rinkian Mobile Belt of West Greenland. *In* Geology of Greenland. *Edited by* A. Escher and W.S. Watt, pages 105-119.

Escher, A., Sorensen, K. and Zeck, H.P.
1976: Nagssugtoqidian Mobile Belt in West Greenland. *In* Geology of Greenland. *Edited by* A. Escher and W.S. Watt, pages 71-95.

Hlava, M. and Krishnan, T.K.
1980: A report on the geological, geophysical and geochemical assessment work, Strange Lake area, Newfoundland-Labrador, NTS 24A/8. Unpublished report, Iron Ore Company of Canada, on file with Newfoundland Department of Mines, Mineral Development Division. [File 24A/8-3]

Hoffman, P.F.
In press: United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Proto-Laurentia. Annual Reviews of Earth and Planetary Sciences, Volume 16.

Hurst, R.W., Morse, S.A., Wheeler, E.P., Runkle, D.E., Saunders, M.J. and Dunlavey, J.T.
1973: Archean anorthosite in Labrador. *In* The Nain Anorthosite Project, Labrador: field report 1973. *Edited by* S.A. Morse, Contribution 13, Geology Department, University of Massachusetts, Amherst, Massachusetts, pages 9-18.

Korstgaard, J., Ryan, B. and Wardle R.
1987: The boundary between Proterozoic and Archean crustal blocks in central West Greenland and northern Labrador. *In* Evolution of the Lewisian and Comparable Precambrian High Grade Terrains. *Edited by* R.G. Park and J. Tarney. Geological Society of London, Special Publication 27, pages 247-259.

Krogh, T.E.
1986: Report to Newfoundland Department of Mines and Energy on isotopic dating results from the 1985-1986 geological research agreement. Newfoundland Department of Mines and Energy, Mineral Development Division. [Open File Lab 707]

Krogh, T.E. and Scharer, U.
1987: Labrador geochronology: Report for Newfoundland Department of Mines and Energy. Newfoundland Department of Mines and Energy, Mineral Development Division, Unpublished report.

Lewry, J.F.
1987: The Trans-Hudson Orogen: extent, subdivision and problems. Geological Association of Canada–Mineralogical Association of Canada Annual Meeting, Saskatoon, Program with Abstracts, Volume 12, pages 67.

Miller, R.R.
1985: Geology of the Strange Lake alkalic complex and the associated Zr-Y-Nb-Be-REE mineralization. *In* Granite-related Mineral Deposits: Geology, Petrogenesis and Tectonic Setting. *Edited by* R.P. Taylor and D.F. Strong. Extended abstracts of papers presented at a CIM Conference on granite-related mineral deposits, Halifax, pages 193-196.

1986: Geology of the Strange Lake alkalic complex and the associated Zr-Y-Nb-Be-REE mineralization. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 11-19.

Monger, J.W.H., Souther, J.G. and Gabrielse, H.
1972: Evolution of the Canadian Cordillera: a plate tectonic model. American Journal of Science, Volume 272, pages 577-602.

Myers, J.S.
1981: The Fiskenaesset anorthosite complex–a stratigraphic key to the tectonic evolution of the West Greenland gneiss complex 3000–2800 m.y ago. *In* Archean Geology. *Edited by* J.E. Glover and D.I. Groves. Special Publication 7, Geological Society of Australia, pages 351-360.

1985: Stratigraphy and structure of the Fiskenaesset Complex, southern West Greeland. Gronlands Geologiske Undersogelse, Bulletin 150, 72 pages.

Nunes, P.D., Steiger, R.H. and Bridgwater, D.
1974: A zircon age from gabbro-anorthosite inclusions in the gneisses of the Angmagssalik area, south-east Greenland. Gronlands Geologiske Undersogelse, Rapport 66, pages 21-31.

Pulvertaft, T.C.R.
1973: Recumbent folding and flat-lying structure in the Precambrian of northern West Greenland. Philosophical Transactions, Royal Society of London, Volume A 273, pages 535-545.

Ramadurai, S., Sankaran, M., Selvan, T.A. and Windley, B.F.
1975: The stratigraphy and structure of the Sittampundi complex, Tamil Nadu, India. Journal of the Geological Society of India, Volume 16, pages 409-414.

Ramsay, J.G.
1967: Folding and Fracturing of Rocks. McGraw-Hill, New York, 586 pages.

Ryan, A.B., Kay, A. and Ermanovics, I.F.
1983: Notes to accompany maps 83-38 to 83-41 showing the geology of the Makkovik Subprovince between Kaipokok Bay and Bay of Islands, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, 21 pages.

Ryan, A.B. and Lee, D.
1986: Gneiss–anorthosite–granite relationships in the Anaktalik Brook–Kogaluk River area (NTS 14D/1,8), Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 79-88.

Ryan, A.B., Lee, D. and Corriveau, L.
1987: Geology of the eastern Churchill Province between Anaktalik Brook and Cabot Lake (NTS 14D/2,6,7), Labrador. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 87-1, pages 155-159.

Searle, M.P.
1983: On the tectonics of the Western Himalaya. Episodes, Volume 1983, pages 21-26.

Taylor, F.C.
1979: Reconnaissance geology of a part of the Precambrian Shield, northeastern Quebec, northern Labrador and Northwest Territories. Geological Survey of Canada, Memoir 393, 99 pages.

van der Leeden, J., Bélanger, M. and Danis, D.
1987: Lithotectonic domains in the high-grade terrain east of the Labrador Trough (Quebec). Geological Association of Canada–Mineralogical Association of Canada, Annual Meeting, Saskatoon, Program with Abstracts, Volume 12, page 98.

Wardle, R.J.
1983: Nain-Churchill Province cross-section, Nachvak Fiord, northern Labrador. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 68-90.

Wardle, R.J. and Bailey, D.G.
1981: Early Proterozoic sequences in Labrador. *In* Proterozoic Basins of Canada. *Edited by* F.H.A. Campbell. Geological Survey of Canada, Paper 81-10, pages 331-359.

Wardle, R.J., Ryan, A.B. and Nunn G.A.G.
1987: Labrador segment of the Trans-Hudson Orogen: crustal development through oblique convergence and collision. *Geological Association of Canada–*Mineralogical Association of Canada, Annual Meeting, Saskatoon, Program with Abstracts, Volume 12, page 99.

Wardle, R.J., Ryan, A.B., Nunn, G.A.G. and Mengel, F.
In press: Labrador segment of the Trans-Hudson Orogen: crustal development through oblique convergence and collision. *In* The Trans-Hudson Orogen of North America: Lithotectonic correlations and Evolution. *Edited by* J.F. Lewry and M.F. Stauffer. Geological Association of Canada, Special Paper.

Wells, P.R.A.
1979: Chemical and thermal evolution of Archean sialic crust southern West Greenland. Journal of Petrology, Volume 20, pages 187-226.

Wiener, R.W.
1981: Tectonic setting, rock chemistry and metamorphism of an Archean gabbro–anorthosite complex, Tessiuyakh Bay, Labrador. Canadian Journal of Earth Sciences, Volume 18, pages 1409-1422.

Williams, H. and Hatcher, R.D.
1983: Appalachian suspect terranes. *In* Contributions to the Tectonics and Geophysics of Mountain Chains. *Edited by* R.D. Hatcher, H. Williams and I. Zietz. Geological Society of America, Memoir 158, pages 33-54.

Windley, B.F.
1973: Archean anorthosites: a review, with the Fiskenaesset Complex, West Greenland as a model for interpretation. Special Publication 3, Geological Society of South Africa, pages 319-332.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines,
Mineral Development Division, Report 88-1, pages 15-36

GEOCHEMICAL CHARACTERISTICS AND MINERAL POTENTIAL OF SPECIALIZED GRANITOID PLUTONS IN THE TRANS-LABRADOR BATHOLITH, EASTERN LABRADOR

Andrew Kerr
Labrador Mapping Section

ABSTRACT

A number of small granitoid plutons in the eastern Trans-Labrador batholith host or are associated with Mo–Cu, Pb–Zn and F mineralization.

These granitoid rocks can be subdivided into the Monkey Hill intrusive suite, Strawberry intrusive suite, and Lanceground intrusive suite. Differences in major element geochemistry are subtle, but the Monkey Hill suite can be distinguished by peraluminous traits that contrast with the metaluminous to locally peralkaline compositions of the other two suites. The Monkey Hill suite is characterized by low levels of F, Ga, Nb, Zr, Y, Zn and REE whereas these are enriched in the Lanceground suite and, to a lesser extent, in the Strawberry suite. The Lanceground suite is distinguished from the Strawberry suite by hypersolvus characteristics, lesser F enrichment and higher Zr, Y and REE levels. Strawberry suite granites also contain anomalous levels of Sn. Patterns for large-ion lithophile elements are similar in all three suites, but absolute levels of Rb, Be, Li and Pb are lower than in Phanerozoic intrusive rocks of similar major element composition.

The Cape Strawberry granite of the Strawberry suite shows regular and unidirectional geochemical zonation related to distance from its outer contact. Silica, U, Rb, Th and Pb increase toward the contact, associated with complementary depletion of Ba, Sr and Li. This is interpreted to reflect in situ *vertical zonation in the roof of a much larger underlying magma chamber, similar to that inferred from compositionally zoned tuffs and widely considered to be a critical part of mineralizing systems in high-silica granites. Similar contactward enrichment of F suggests that a volatile phase played a role in developing zonation.*

The Strawberry and Lanceground suites are comparable in some respects to potassic, fluorine-enriched rocks that are variably termed 'anorogenic', 'A-type' or 'within-plate' granites, and are typically associated with Mo–Sn, F, U and Pb–Zn mineralization. The most promising units for exploration are those which preserve original intrusive contacts with their host rocks, and in which contactward geochemical enrichment patterns suggest significant mass transport of incompatible elements.

INTRODUCTION

Project Description

This project was initiated in 1984 to provide an assessment of the mineral potential of granitoid rocks throughout the eastern Central Mineral Belt and to develop an understanding of the evolution and petrogenesis of the ca. 1.65 Ga old Trans-Labrador batholith (Figure 1).

An important component of the project is a large-scale geological mapping and lithogeochemistry program utilizing a 2 by 2 km grid-cell approach similar to that employed in Newfoundland granitoid terranes (e.g., Dickson, 1983; Tuach *et al.*, 1986). Follow-up work has emphasized mapping and more detailed sampling with an average site spacing of 750 m to 1 km. This is intended to delineate possible specialized granitoids and to define geochemical zonation patterns in or around units that may pinpoint favourable loci for mineralization.

The study area is centred around the small village of Makkovik, and covers approximately 10,000 km². Northern and eastern portions are dominated by a deeply incised coastline and a rugged hinterland rising to 900 m above sea level. A monotonous drift-covered plateau is present in the southwest and southeast of the area. Access to the area is by scheduled air service (LABAIR) or Marine Atlantic coastal boat.

Previous Work

Compilation and synthesis of 1:50,000 and 1:100,000 scale mapping by the Newfoundland Department of Mines is presented by Gower *et al.* (1982) for the eastern part of the

---

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

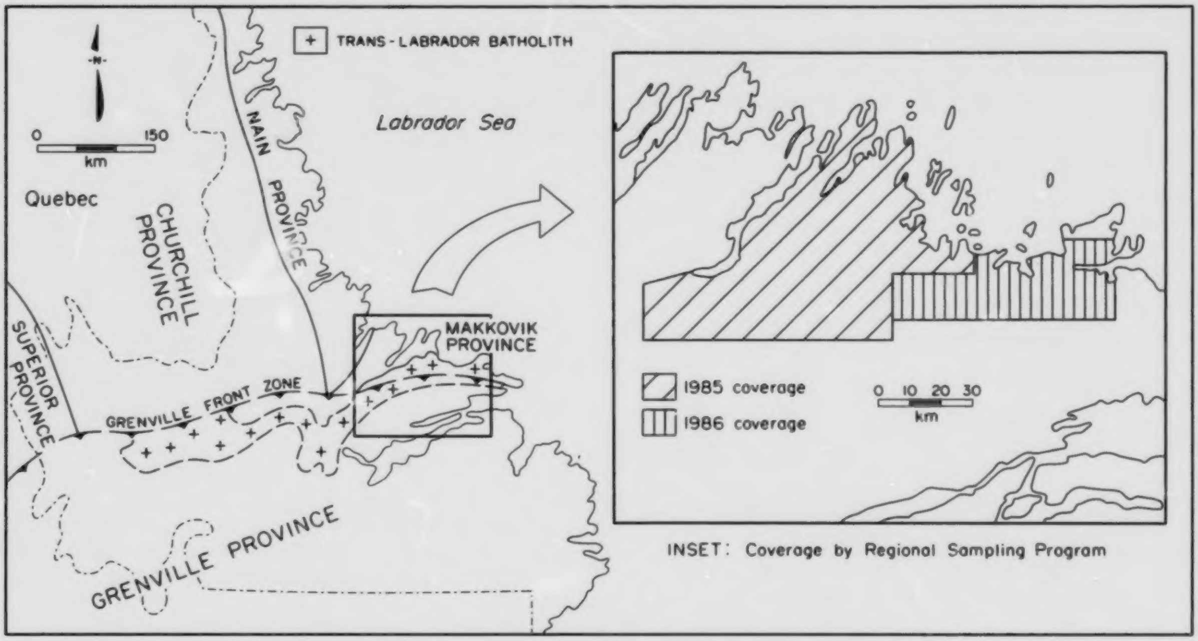


Figure 1. *Location map showing coverage by regional sampling and mapping programs carried out in 1985 and 1986.*

area, and by Bailey (1979) and Ryan (1985) for the west. These workers provide detailed reviews of geological work prior to the mid-1970's. Mineral exploration by Brinco was semicontinuous from 1955 to 1980, and was mostly directed at uranium, although some evaluation of Mo–Cu and Pb–Zn prospects took place.

Geological mapping during the 1985 field season led to the revision of existing subdivisions and establishment of new granitoid units (Kerr, 1986). Subsequent interpretation of geochemical data from the regional program allowed the identification of several granite plutons showing geochemical characteristics suggesting metallogenic specialization (Kerr, 1987a). This report subdivides these granites and gives an account of their petrology and geochemistry.

GEOLOGY AND PETROLOGY

Geological Overview

The geology of the area is reviewed in detail by Gower *et al.* (1982) and the distribution of granitoid units is summarized in previous reports (Kerr, 1986, 1987a). Figure 2 illustrates the distribution of specialized granitoid plutons and also the major geological divisions described below. Most of the area lies within the Makkovik structural province (Gower and Ryan, 1986), although the southeastern portion forms part of the Grenville Province. The boundary between the two structural provinces is marked by the major east-trending Benedict Fault system. Four geological assemblages are present within the Makkovik Province:

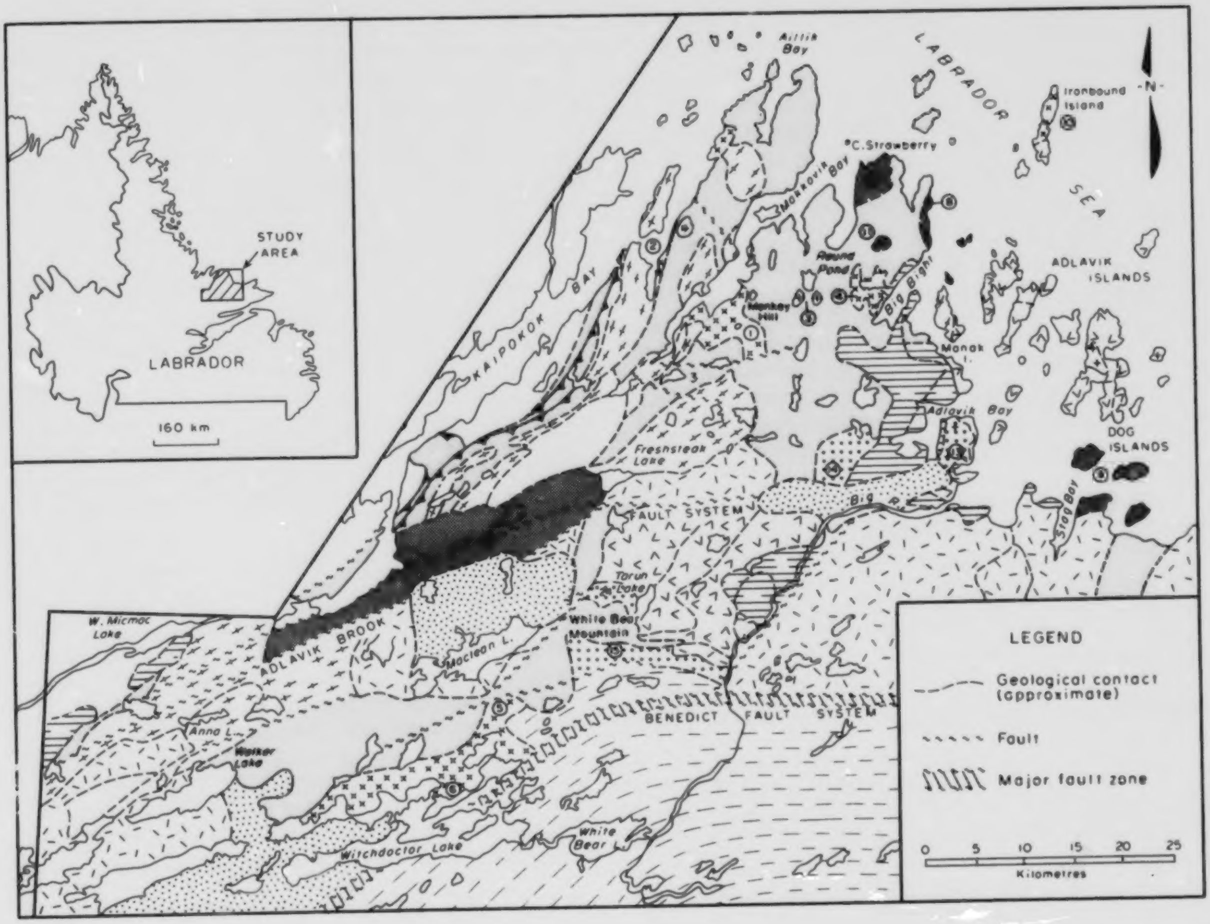
1) High-grade quartzofeldspathic gneisses of probable Archean age that underwent substantial reworking at ca. 1.85 Ga.

2) Supracrustal rocks of the *Aillik Group*, which structurally overlie the Archean, and were perhaps developed as a cover sequence upon it. They consist of a lower metasedimentary–mafic volcanic assemblage in a thrust belt along Kaipokok Bay, and a structurally overlying and much thicker upper felsic volcanic–volcaniclastic assemblage. Contacts between the two components are tectonic and they do not neccessarily represent a single stratigraphic sequence.

3) Foliated granitoid intrusive rocks of the *Makkovikian batholith*, which intrude the Aillik Group, but share at least the later portion of its deformational history. The batholith is thus broadly syntectonic with respect to the ca. 1.85 Ga Makkovikian Orogeny, which affected the Aillik Group and underlying basement.

4) Posttectonic intrusive rocks of the *Trans-Labrador batholith* (TLB), thought mostly to be of ca. 1.65 Ga age (Wardle *et al.*, 1986). These can be divided into 3 components:

   (i) the *Adlavik Intrusive Suite*, comprising layered gabbro and diorite, with spatially associated monzonite and syenite;


STUDY AREA
LABRADOR
160 km
Aillik Bay
LABRADOR SEA
Ironbound Island
-N-
C. Strawberry
Makkovik Bay
Round Pond
Big Bight
Monkey Hill
ADLAVIK ISLANDS
Monak I.
Adlavik Bay
DOG ISLANDS
Stag Bay
Big R.
KAIPOKOK BAY
Freshsteak Lake
FAULT SYSTEM
Torun Lake
White Bear Mountain
ADLAVIK BROOK
Maclean L.
W. Micmac Lake
Anna L.
Walker Lake
BENEDICT FAULT SYSTEM
Witchdoctor Lake
White Bear
LEGEND
Geological contact (approximate)
Fault
Major fault zone
0 5 10 15 20 25
Kilometres

QUATERNARY

░ Drift deposits

MIDDLE PROTEROZOIC

TRANS-LABRADOR BATHOLITH

Unspecialized Granitoid Suites

▤ **Grenville Province gneisses:** *strongly deformed granitoid rocks (probably equivalent to the Trans-Labrador batholith)*

▨ **Regional granitoid units:** *quartz monzonite, granodiorite, granite*

Adlavik Intrusive Suite

▨ *Monzonite, quartz monzonite, syenite*

▤ *Gabbro, diorite*

Specialized Granitoid Suites

⁙ **Lanceground intrusive suite:** *medium to coarse grained, K-feldspar-porphyritic, quartz syenite to alkali-feldspar granite*

■ **Strawberry intrusive suite:** *coarse grained, K-feldspar-porphyritic, biotite granite and alkali-feldspar granite containing accessory fluorite*

× × × **Monkey Hill intrusive suite:** *fine to medium grained leucocratic monzogranite and granite*

EARLY PROTEROZOIC

☐ **Aillik Group:** *dominantly felsic volcanic and volcaniclastic rocks with subordinate mafic volcanic and metasedimentry rocks*

▤ **Makkovikian batholith:** *variably foliated monzonite, quartz monzonite, granodiorite and granite.*

ARCHEAN

☐ *Quartzofeldspathic gneiss and migmatite*

Figure 2. *Generalized geological map of the study area, showing the distribution of specialized granites and the locations of individual units discussed in this report. Circled numbers refer to units listed in Table 1.*

(ii) areally extensive *'regional'* granitoid units, comprising compositionally variable quartz monzonite, granodiorite and granite; and

(iii) *'smaller'* plutons, comprising discordant bodies of syenite, granite and alkali feldspar granite that commonly show well-preserved contacts with the Aillik Group. Several of these display specialization, and some are mineralized.

Smaller plutons associated with mineralization are mostly in the north, whereas regional granitoid units are mainly in the central portions of the area (Figure 2). This is interpreted to reflect the exposure of different levels of the TLB across a series of major east-trending faults of Grenvillian age. The northern portion of the area represents the uppermost surface of the batholith and enclosing country rocks, whereas progressively deeper levels are exposed southward.

Adjacent to and south of the Benedict Fault system, well-preserved intrusive rocks give way to foliated to gneissic granitoid rocks that are presumed to represent their deep-level deformed equivalents. North of this boundary, local east-trending fabrics and mylonitic zones suggest some Grenvillian deformation, but these effects are weak or absent in the northernmost structural blocks.

Definition and Classification of Specialized Granitoid Rocks in the Study Area

Several granitoid plutons within the TLB are considered to be 'specialized granites' (cf. Tischendorf, 1977). Specialization, as used in this study, is a *relative* characteristic, and is defined in terms of a contrast with regional geochemical background. As a whole, the TLB displays lower levels of incompatible and higher levels of compatible trace elements than younger rocks of equivalent major element composition (e.g., Tuach *et al.*, 1986); thus trace-element signatures of specialized rocks are less extreme. The definition employed for the TLB is as follows:

1) SiO_2 > 71.5%, (MgO + CaO) < 1.5%, FeO(t) < 1.8 %;

2) relatively enhanced Levels of F (1000-5000 ppm), Rb (180-500 ppm), Zr (250-2500 ppm), Th (15-60 ppm), and other lithophile trace elements;

3) relatively reduced levels of Sr (10-160 ppm), Ba (50-400 ppm), V (2-15 ppm), and other compatible trace elements;

4) relatively low K/Rb (50-150), high Rb/Sr (2-15), low Ba/Be (20-100) ratios; and

5) direct or spatial association with mineralization (this overrides the above).

Plutons in which most samples fit a majority of these charcteristics are considered to be specialized in terms of their regional environment. A feature that also appears to be associated with specialization is an extreme disorganization of trace-element patterns, particularly at SiO_2 contents of 72 percent and above. The geographic groupings established by these criteria do, however, include individual samples or areas that do not strictly meet this definition. Trace-element characteristics listed above are variably developed in the specialized rocks, and assist in their classification.

Three suites of specialized granites can be distinguished on both petrological and geochemical grounds. They are termed the Monkey Hill intrusive suite, Strawberry intrusive suite and Lanceground intrusive suite. Figure 2 shows the distribution of these suites and their individual components. They can be differentiated on both petrological and geochemical grounds, which are briefly summarized in Table 1. Showings related to these granites are located and described by Kerr (1987a).

Monkey Hill Intrusive Suite

Distribution. This suite is composed of eight discrete bodies, which lie in two main geographic zones. The type area is in the north, where the Monkey Hill, Duck Island, Round Pond and Little Monkey Hill granites, and a number of small unnamed bodies, intrude the Aillik Group. The similar Witchdoctor and Burnt Lake granites lie in the southwest of the area, within a downfaulted structural block that also exposes Aillik Group country rocks. The Kidlaluit granite, exposed on the larger of the Ironbound Islands, was grouped by Kerr (1987a) with the Cape Strawberry granite, but has been tentatively reassigned to the Monkey Hill suite on the basis of geochemistry.

Field relations and petrology. In its type area, the suite is characterized by fine grained, grey to pink or white, leucocratic monzogranite and alaskitic granite, locally containing small plagioclase phenocrysts. The main body is characterized by an overall textural and compositional homogeneity, and appears to consist of a single intrusive phase, although cognate inclusions are present in marginal areas (Plate 1a). Chlorite aggregates form the dominant mafic phase, and contain cores of pale biotite suggesting a largely secondary origin. Sparse accessory minerals include sphene, zircon, allanite and rare fluorite.

Other component units in the north of the area show similar characteristics to the type locality, and probably represent salients or cupolas on the upper surface of a larger interconnected plutonic body. The Round Pond granite and the Duck Island granite host, or are spatially related to mineralization, and are locally miarolitic and/or pegmatitic.

Contacts with the Aillik Group and Makkovikian batholith are well exposed in many locations, and appear as sharp, discordant intrusive contacts characterized by stoping

Table 1. Component bodies and general characteristics of the three suites of specialized granites in the Trans Labrador batholith

NAME	MONKEY HILL SUITE	STRAWBERRY SUITE	LANCEGROUND SUITE
COMPONENT INTRUSIVE BODIES	NORTHERN AREA: Monkey Hill granite (1) Duck Island granite (2) Round Pond Granite (3) Little Monkey Hill granite (4) Kidlaluit granite ? (10) assorted minor intrusions SOUTHERN AREA: Burnt Lake granite (5) Witchdoctor granite (6)	TYPE AREA: Cape Strawberry granite (7) October Harbour granite (8) Poodle Pond Granite (11) Kidlaluit granite ? (10) EASTERN AREA: Dog Island granite (9) SOUTHERN AREA: Bayhead granite (12)	ADLAVIK BAY AREA: Lanceground Hills granite (13) Pistol Lake granite (14) SOUTHERN AREA: Tarun granite (15)
GENERAL FEATURES	Fine- to medium-grained monzogranite and alaskitic granite. Locally plagioclase porphyritic.	Coarse grained pink to orange granite and alkali feldspar granite with K-feldspar phenocrysts.	Coarse grained buff to pink quartz syenite to alkali-feldspar porphyritic granite.
MAFIC MINERALOGY	Chlorite, derived from biotite. Muscovite/garnet in southern area.	Biotite, variably altered to chlorite. Accessory fluorite, lesser zircon and allanite.	Biotite with lesser hornblende Accessory zircon and allanite, with lesser fluorite.
REPORTED MINERALIZATION	Endocontact disseminated Mo. Exocontact vein-style Mo–Cu, also Pb–Zn, U, F and Au	Endocontact disseminated Cu-Pb exocontact Pb–Zn–Ag veins, and stockwork-type Mo.	Uncertain. Possible spatial association with vein-style Cu–Ag–U mineralization.

NOTE: Numbers in parentheses refer to locations on Figure 2.

and net veining of the country rocks. Narrow (<50cm) 'tuffisite' breccia zones with biotite-rich matrix (Plate 1b) indicate violent exsolution of dissolved volatile components and a relatively high level of emplacement. Contact metamorphic effects are minimal or nonexistent. However, this may largely be a reflection of the unreactive nature of the surrounding felsic volcanic and granitoid rocks. Calcic skarn assemblages with orange calcite, diopside, andradite garnet and local specularite are developed where amphibolitic rocks are adjacent to contacts.

The southern zone of the Monkey Hill suite is represented by the Burnt Lake and Witchdoctor granites, which form a continous body within a structural block dominated by Aillik Group felsic volcanic rocks. This is inferred to represent a downfaulted area where higher levels of the TLB are locally preserved. The Burnt Lake granite is a fine grained, equigranular, grey to pink, alaskitic leucogranite containing biotite, chlorite, muscovite and minor garnet. It displays a sharp intrusive contact with metarhyolites of the Aillik Group in some areas (MacKenzie and Wilton, 1987), but has also been described as showing gradational contacts (Bailey, 1979). The Witchdoctor granite is a poorly exposed unit that consists largely of medium grained, equigranular leucogranite and alkali feldspar granite containing minor muscovite and garnet in addition to biotite. The mineralogical and chemical similarities suggest a close relationship between the two, and the Burnt Lake granite is interpreted to be a fine grained roof phase to the Witchdoctor granite.

Mineralization. Both geographic zones are associated with mineralization. In the north, the most significant deposits are associated with the Round Pond granite, which has a halo of hydrothermal quartz and carbonate veins containing Mo, Cu, Zn, Pb, U and F, and minor Ba and W. Distribution and mineralogy of the vein swarm appear to be zoned with distance from the easternmost of the two stocks in the area. Detailed descriptions of this mineralization are presented by MacDougall *(in preparation)* and MacDougall and Wilton (1987). Disseminated molybdenum mineralization (up to 0.5–1.0 percent Mo) is also present in miarolitic granites of the Duck Island stock (Gower *et al.*, 1982; Kerr, 1987a). This small (500 by 500 m) body represents a cupola intruding deformed Makkovikian granitoids, and is at the centre of an extensive area of granitoid veins and sheets that suggest a larger body is close to surface over several square kilometres.

In the southern zone, a similar small but high-grade molybdenum showing is hosted by the Burnt Lake granite at its contact with the Aillik Group, and MacKenzie and Wilton (1987) suggest that a phase of Pb–Zn–F mineralization within adjacent Aillik Group rocks may also be related to the granite.

Significant molybdenum mineralization at the Cape Aillik prospect, which contains some 2 million tonnes of 0.25 percent Mo, is considered by Wilton *et al.* (1986) and Wilton and Wardle (1987) to be of 'granophile' aspect, as it is formed by discordant veins and fracture fillings within an older

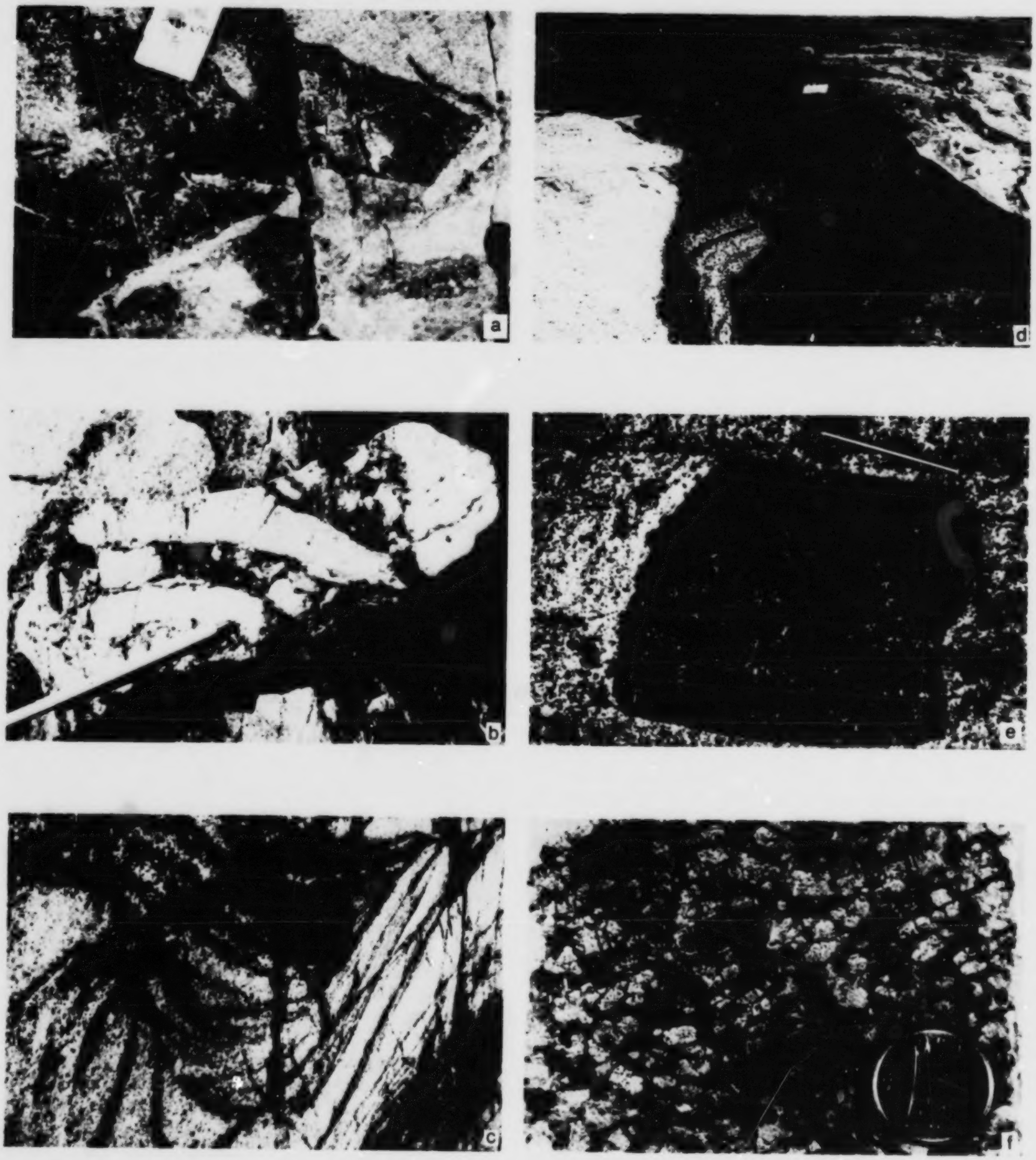


Plate 1. *Field characteristics of specialized granitoid plutons in the Trans-Labrador batholith; (a) cognate xenoliths (dark) disrupted by the main phase of the Monkey Hill granite; (b) 'tuffisite' breccia from the Monkey Hill granite; (c) distinctive trough crossbedded mafic layers of cumulate origin, Cape Strawberry granite; (d) megaxenolith of rhythmically layered granite in the Cape Strawberry granite; (e) xenolith of fine grained phase in Cape Strawberry granite, note breccia veinlet; (f) typical feldspar-porphyritic texture of the Pistol Lake granite, part of the Lanceground intrusive suite.*

stratiform shear zone. They suggest that an apophysis of the Cape Strawberry granite (see below) might be present beneath the prospect. A number of granitoid sheets and dykes exposed within the deposit area attest to the proximity of a magma chamber, but these minor intrusions bear a closer resemblance to the Monkey Hill suite. Wilton and Wardle (1987) suggest a similar origin for a number of disseminated and skarn-like U–Mo–F showings around Makkovik. These could be related to granites of either the Monkey Hill or Strawberry suites.

Strawberry Intrusive Suite

Distribution. The Strawberry intrusive suite is the most widespread and distinctive of the three suites. It consists of at least six discrete bodies within the area covered by Figure 2, and also probably includes rocks present as far as Cape Harrison, some 75 km to the east. The type area is on the peninsula north-east of Makkovik, where the Cape Strawberry, October Harbour and Poodle Pond granites, together with numerous similar veins and dykes, intrude Aillik Group metavolcanic rocks. About 20 km to the east, the Dog Island granite underlies a number of islands, and may be continous eastward with the Tukialik granite of the Benedict Mountains (Gower, 1981; Kerr, 1987b).

The largest individual body within the suite is the Bayhead granite, which outcrops around the inner reaches of Kaipokok Bay. This was previously grouped with the 'regional' granitoid units by Kerr (1987a), and is unspecialized or marginally specialized by the criteria listed above. It is, however, very similar in mineralogy and texture to northern components of the suite, and is inferred to represent a deeper level section through a magma chamber typical of the suite. It has thus been retained as part of the Strawberry intrusive suite.

Field relations and petrology. The Strawberry intrusive suite is predominantly medium- to coarse-grained, pink to orange, quartz-rich granite and alkali feldspar granite that commonly displays porphyritic to megacrystic textures. The most common phenocryst phase is perthitic microcline, but parts of the Dog Island granite are variably quartz porphyritic. Plagioclase is present as a discrete (usually groundmass) phase and as lamellae in coarse perthite. The dominant mafic phase is biotite, which is variably altered to chlorite. A few samples contain relict grains of pale-green amphibole rimmed by biotite aggregates. Some finer grained granites near contact zones contain blue reibeckitic or arfvedsonitic amphibole, as do (metasomatised ?) lithologies that may have been originally Aillik Group metavolcanic rocks. Purple fluorite is present in interstitial patches, along fractures, and intergrown with biotite–chlorite–zircon–iron oxide aggregates. Accessory phases include euhedral apatite, sphene, zircon and allanite.

The Strawberry suite exhibits considerable local textural variety, including both fine grained granite and rocks with very coarse pegmatitic textures, in addition to the dominant coarse grained facies. Such variety is most evident in the type area at Cape Strawberry, whereas the Bayhead and Dog Island granites are more homogeneous. Two phases of coarse grained granite can be distinguished locally in the Cape Strawberry granite, but there is little textural or mineralogical contrast away from their mutual contacts; they probably represent minor chilling effects. Mafic mineral accumulations indicative of cumulate processes (Plate 1c) are found in the Cape Strawberry, Dog Island and Bayhead granites. These consist of trough crossbedded accumulations of euhedral amphibole and biotite, and lesser amounts of euhedral zircon and allanite. The Cape Strawberry granite also contains a large (cognate ?) block of rhythmically layered granite (Plate 1d) showing similar characteristics. These features suggest a low viscosity during crystallization of Strawberry suite magmas.

Intrusive contacts with the Aillik Group are best exposed in the type area, where they vary from clean, sharp, discordant contacts to zones of extensive interaction and hybridization. Fine grained, miarolitic phases are developed close to the contacts, but rarely exceed a few tens of metres in thickness. Xenolith-rich zones are also developed, with xenoliths of unaltered Aillik Group, fine grained granite and rock types that appear to represent 'granitized' Aillik Group. Margins of the October Harbour granite are particularily xenolith rich, and granite adjacent to the contact contains a green-brown (calcic ?) garnet probably derived by assimilation of skarnoid patches developed in local amphibolitic country rocks. Brecciated zones, indicative of volatile exsolution, are developed in xenoliths and outcrops adjacent to contacts (Plate 1e). Aillik Group lithologies near contacts are variably recrystallized and fluoritic, and are locally difficult to distinguish from fine grained phases of the granite. Alteration, bleaching and pyritization are evident, and suggest the passage of hydrothermal fluids. Amphibolitic units develop calcite–diopside–garnet skarn zones, some of which contain up to 2 percent fluorine.

The distribution of granite bodies in the type area suggests that a more extensive body lies just below the surface, and the small Poodle Pond granite consists of a composite sill or laccolith of fine grained granite above a feeder dyke presumably connected to this body at depth.

Numerous minor intrusions are present between Makkovik and the Adlavik Islands, and include a variety of single phase and composite dykes, pegmatites, aplites and quartz–feldspar porphyries. Many are fluorite bearing or show geochemical patterns suggesting that they are part of the Strawberry suite and provide evidence of a more continous body at depth. Porphyry dykes are also associated with the Dog Island granite, and fresh rhyolite and felsite sills are present within the Bayhead granite. Some of these minor intrusions may represent feeders to cogenetic volcanic sequences now removed by erosion.

Mineralization. Most of the mineralization associated with the Strawberry intrusive suite is external to its contacts. The Cape Strawberry granite itself is associated with a number of low-grade molybdenum showings and pyritic gossans around its southern contact (Figure 2) and on the peninsula west of Ford's Bight (Wilton *et al.*, 1986; Wilton and Wardle, 1987). Some of these display a stockwork style of deposition and are associated with pyrite, fluorite and molybdenite-bearing pegmatites and aplites that are probably offshoots of the granite. Irregular vein-like siliceous and/or biotite-rich zones near contacts of the granite contain elevated but uneconomic levels of Mo, Zn and F over narrow widths. Significant Pb, Zn, Ag and Au mineralization, associated with fluorite and barite, is present in a group of discordant carbonate-hosted veins east of Big Bight, (Wilton and Wardle, 1987). The mineralized zone is equidistant from contacts of the Cape Strawberry, October Harbour and Poodle Pond granites, and is presumably underlain at shallow depths by granite, although none is exposed in trenches.

The Dog Island granite hosts a small, low-grade, disseminated Cu−Pb−F occurrence associated with the margins of an aplitic vein cutting coarse-grained granite. Anomalous levels of Sn (116 g/t) are also present in this showing.

The Bayhead granite is bounded mostly by faults and is not known to host mineralization. It contains irregular zones of moderate to locally intense hematization that suggest mild hydrothermal activity. Fine grained fluoritic phases are present at the southeastern extremity of the unit, and may suggest the presence of an intrusive contact with older Makkovikian granitoid rocks in this area.

Lanceground Intrusive Suite

Distribution. The Lanceground intrusive suite consists of three discrete bodies. The Lanceground Hills and Pistol Lake granites are located east and west of Adlavik Bay respectively, whereas the Tarun granite is inland, south of White Bear Mountain. All three geographic zones of the Lanceground suite are spatially associated with gabbro, monzonite and syenite assigned to the Adlavik Intrusive Suite.

Field relations and petrology. The characteristics of the suite are best known from the Adlavik Bay area, where deformation is relatively minor. In the Tarun granite, Grenvillian deformation variably obliterates original textures and relationships. The Lanceground Hills and Pistol Lake granites consist of medium- to coarse-grained grey to buff-pink quartz syenite to alkali felspar granite, containing phenocrysts of coarse perthite (Plate 1f). Both are hypersolvus granites commonly lacking discrete plagioclase, and are richer in mafic phases than granites of the Monkey Hill and Strawberry suites. The dominant mafic phase is red-brown biotite, although hornblende is usually present. A few samples contain relict fayalitic olivine, extensively altered to amorphous iron oxide−hydroxide (iddingsite). Samples lacking fayalite often contain irregular red-brown patches that may be pseudomorphs after it. Abundant accessory phases include interstitial fluorite and large (1 to 2 mm) euhedral sphene, zircon and allanite. Reibeckitic amphibole is present in some examples, and a red-brown prismatic phase (aenigmatite?) is locally associated with it. The Tarun granite is strongly recrystallized in places; the best preserved examples resemble granites from the Adlavik Bay area, but lack fayalite.

The Lanceground Hills granite intrudes diorite and quartz monzonite of the Adlavik Intrusive Suite. Most coastal exposures correspond with a complex polyphase agmatitic zone in the older rocks, and it is difficult to distinguish individual intrusive components. However, dykes of buff quartz syenite and granite, which cut this zone, clearly belong to the Lanceground granite. The Pistol Lake granite is in contact with the Aillik Group for over 10 km, but much of this is obscured by drift. The contact is sharp and intrusive in the few locations where it has been observed, and the granite has a finer groundmass than normal, suggesting marginal chilling. The Tarun granite is in contact with the Aillik Group around White Bear Mountain, but contacts have not been observed. East-trending faults related to the Benedict Fault system are prominent in this area, and it is likely that some of these contacts are tectonic.

Mineralization. The three component bodies of the Lanceground intrusive suite lie outside the areas explored in detail by BRINCO Limited, and data concerning mineralization are scanty. A U−Cu−Ag showing within the Aillik Group (7-11 showing) lies close to the contact of the Pistol Lake granite. This is reported to have a discordant vein-like form (Wilton *et al.*, 1987), and may be related to the granite. Analysis of samples by Wilton *et al.* (1987) and recent work by Cuvier Mines Limited suggest some potential for gold in this occurrence. A number of uranium showings in the area are also close to the contact of the Pistol Lake body. A dyke of fine- to medium-grained granite near the entrance to Adlavik Bay, probably related to the Lanceground Hills granite, contains 2400 ppm Zr and 170 ppm Y. No mineralization is known in or around the Tarun body.

DESCRIPTIVE GEOCHEMISTRY

Analytical Methods

Samples were analyzed for major elements and a range of trace elements in the Department of Mines laboratory, and also by Bondar-Clegg Limited. The element suite and methods are listed in Table 2. Numerical data and analyses of precision and reproducibility are presented in Kerr *(in preparation)*.

Table 2 shows the average compositions of the three specialized suites described above, and also the average composition of regional units inferred to represent deeper levels of the batholith. The Bayhead granite has been separated from other members of the Strawberry suite as it shows a significantly different major-element composition. Median values representing the 50th percentile are also shown to give a better measure of 'average' levels of trace elements, which mostly have strongly log-normal distributions. For some major elements, notably SiO_2 and MgO, medians are also significantly different from arithmetic means.

Table 2. Average major- and trace-element compositions of granitoid rocks discussed in this report

Oxide weight percent	Regional Units			Monkey Hill Intrusive Suite			Strawberry Intrusive Suite (Excluding Bayhead Granite)			Strawberry Intrusive Suite (Bayhead Granite Only)			Lanceground Intrusive Suite		
	(n=131 or n=32)*			(n=85 or n=51)*			(n=82 or n=50)*			(n=47 or n=11)*			(n=64 or n=26)*		
	MEAN	MEDIAN	S.D.	MEAN	MEDIAN	S.D.	MEAN	MEDIAN	S.D.	MEAN	MEDIAN	S.D.	MEAN	MEDIAN	S.D.
SiO_2	67.33	68.20	5.61	73.87	74.20	2.47	72.62	73.35	2.93	69.90	71.40	5.42	72.13	72.22	2.98
TiO_2	0.53	0.47	0.30	0.13	0.12	0.10	0.23	0.22	0.11	0.43	0.30	0.34	0.34	0.30	0.20
Al_2O_3	15.15	15.12	1.65	13.65	13.50	1.15	13.47	13.50	1.40	13.87	13.69	1.34	13.06	12.90	1.23
Fe_2O_3	1.43	1.31	0.81	0.66	0.50	0.50	0.97	0.72	0.68	1.05	0.79	0.73	1.26	1.25	0.58
FeO	2.11	1.68	1.38	0.52	0.47	0.33	1.28	1.14	0.76	2.37	2.03	1.44	1.54	1.36	0.92
MnO	0.07	0.07	0.03	0.05	0.04	0.03	0.05	0.04	0.03	0.07	0.05	0.05	0.07	0.06	0.04
MgO	0.91	0.70	0.99	0.17	0.14	0.12	0.22	0.18	0.25	0.52	0.22	0.65	0.20	0.15	0.18
CaO	2.24	1.82	1.66	0.74	0.64	0.35	0.84	0.79	0.46	1.52	1.08	1.16	0.92	0.75	0.51
Na_2O	4.15	4.18	0.59	4.17	4.09	0.87	4.15	3.95	0.93	3.87	3.78	0.60	3.92	3.97	0.51
K_2O	4.78	4.88	1.00	4.96	4.87	0.83	5.12	5.16	0.98	5.12	5.23	0.92	5.48	5.40	0.54
P_2O_5	0.16	0.13	0.11	0.03	0.02	0.02	0.04	0.04	0.03	0.10	0.04	0.11	0.05	0.04	0.05
LOI	0.70	0.67	0.33	0.54	0.53	0.21	0.60	0.57	0.27	0.57	0.57	0.18	0.55	0.55	0.21
Element (ppm)															
Li	21.1	19.0	12.0	20.6	16.0	15.9	28.2	20.5	23.5	23.2	16.0	19.4	14.0	11.0	12.6
Rb	129.0	129.0	47.7	189.9	182.0	66.0	188.4	185.0	52.7	156.7	143.0	61.8	172.4	169.0	40.0
Cs	2.9	2.0	2.4	2.0	2.0	1.3	1.3	1.0	0.5	1.7	2.0	0.9	1.3	1.0	0.5
Be	3.6	3.6	1.1	4.8	4.6	1.4	4.9	5.1	1.1	3.7	3.0	1.7	5.5	4.9	2.1
Sr	295.6	218.0	209.2	119.1	85.0	191.3	83.7	77.5	69.1	119.3	76.0	114.7	61.2	35.5	69.3
Ba	944.4	881.0	467.0	444.6	340.0	502.9	382.0	427.0	232.6	673.7	661.0	436.1	333.1	258.0	267.7
Ga	16.4	17.0	5.1	11.8	11.0	5.5	18.3	19.0	6.9	17.6	20.0	6.3	21.8	22.5	10.2
Sn	2.8	2.0	2.6	1.9	1.0	1.6	5.5	5.0	3.6	4.3	4.0	2.5	3.7	3.0	2.6
Pb	18.7	16.0	12.1	24.2	24.0	9.7	25.2	24.5	12.7	24.8	24.0	7.3	24.9	23.0	14.6
As	1.6	1.0	1.4	1.3	1.0	0.8	1.8	1.0	2.0	1.3	1.0	0.5	1.5	1.0	0.9
Sb	0.3	0.2	0.2	0.2	0.2	0.1	0.3	0.2	0.2	0.3	0.2	0.1	0.3	0.2	0.1
F	695.4	696.0	377.6	377.5	225.0	386.6	1491.9	1412.0	965.6	970.0	797.0	761.5	1327.5	1213.0	921.8
Sc	4.8	3.7	3.3	1.7	1.3	1.3	2.7	2.4	2.0	2.4	1.6	1.8	4.5	2.6	7.1
V	35.0	22.0	39.5	11.3	11.0	9.7	11.5	10.0	9.8	15.9	10.0	21.7	8.4	7.0	8.4
Cr	6.3	3.0	13.8	3.0	2.0	2.8	4.2	2.0	6.1	4.8	3.0	5.0	4.0	4.0	2.5
Co	6.5	3.0	11.1	1.1	1.0	0.3	1.8	1.0	1.8	3.8	1.0	4.7	1.4	1.0	0.7
Ni	2.5	1.0	4.3	1.3	1.0	1.4	1.5	1.0	3.3	2.3	1.0	3.8	1.5	1.0	1.4
Cu	17.4	6.0	72.7	6.8	2.0	16.1	8.6	3.0	36.8	4.6	3.0	4.4	6.5	4.0	10.3
Zn	61.8	56.0	28.3	30.9	31.0	15.0	71.0	57.0	65.7	73.6	73.0	31.9	93.2	85.0	56.3
Y	38.2	37.0	17.3	27.3	22.0	24.0	55.5	44.5	40.0	55.0	54.0	21.6	78.1	80.5	32.3
Zr	200.1	189.0	102.8	148.0	138.0	69.1	314.0	255.0	213.0	246.1	240.0	97.0	416.9	377.5	284.4
Nb	16.1	15.0	7.2	18.7	17.0	11.2	27.4	22.0	26.8	25.1	25.0	9.9	29.8	29.0	11.0
Mo	3.6	3.0	2.1	80.3	2.0	531.8	3.3	3.0	1.9	4.4	4.0	1.8	4.3	4.0	2.3
La	58.9	54.0	27.0	25.1	19.0	22.6	85.1	91.5	45.2	91.4	76.0	56.3	128.1	117.5	61.0
Ce	115.8	103.0	53.8	51.1	39.0	46.4	167.1	179.0	79.9	180.5	143.0	102.8	257.8	248.5	120.1
Sm	9.9	9.3	4.0	4.1	3.6	2.6	12.6	11.5	5.9	12.8	11.0	7.6	20.1	19.9	11.7
Tb	1.5	1.0	0.7	1.2	1.0	0.6	1.8	1.5	1.1	2.3	2.0	1.1	3.1	3.0	1.9
Yb	5.4	5.0	0.8	5.1	5.0	0.4	7.1	6.0	3.5	6.5	6.0	1.8	9.0	8.5	4.8
Lu	1.0	1.0	.0	1.0	1.0	.0	1.2	1.0	0.4	1.1	1.1	0.2	1.4	1.3	0.6
Hf	10.9	8.0	12.4	5.1	5.0	1.7	12.5	11.0	5.2	10.3	10.0	4.8	21.5	21.0	14.6
Ta	1.5	1.0	0.7	1.5	1.0	0.8	1.7	1.5	0.9	2.0	2.0	1.1	1.8	2.0	0.9
W	2.0	2.0	0.2	2.0	2.0	0.0	2.0	2.0	0.0	2.2	2.0	0.6	4.2	2.0	7.7
Th	12.5	10.0	10.8	15.3	16.0	9.3	21.9	17.0	23.6	17.4	14.0	16.9	18.5	20.0	7.2
U	4.2	3.7	2.3	6.4	4.7	5.3	6.7	5.2	8.3	4.7	3.5	4.1	5.4	5.3	2.0
K/Rb	330	320	85	241	221	86	240	235	67	304	293	110	275	264	60
Rb/Sr	1	0.5	1.6	3.9	2.2	4.8	4.6	2.5	5.2	5.3	2.2	16.5	7.3	4.5	9.4
Ba/Rb	9	7	7.1	3.2	1.7	5.3	2.6	2.2	4.4	5.4	3.53	4.9	2.1	1.5	1.8
Ga/Al_2O_3	1.1	1.1	0.4	0.9	0.8	0.4	1.4	1.4	0.6	1.3	1.4	0.4	1.7	1.7	0.8

* n—number of samples; S.D.—standard deviation; ppm—parts per million. Major elements and Ba, Cu, Zn, Pb, Sr, Ni, Li, Rb, Cr, V, Be, Mo and Cu analyzed by atomic absorption. ICP spectroscopy used for Ga, Nb, Zr, Th, Y, La and Ce, INAA for U and ion-selective electrode for F. Data for Sc, As, Cd, Sb, Cs, Sm, Tb, Yb, Lu, Hf, Ta, W and Sn obtained by Bondar-Clegg Limited by INAA (XRF for Sn). Values for these elements obtained on a smaller data set than for internal analysis. The smaller of the two figures for number of observations at the head of each column refers to this data set.

Major-Element Variation Patterns

Figure 3 shows the distribution of selected major elements and derived ratios for the three suites, which are each subdivided to show different bodies or geographic areas. Differences in major-element geochemistry between the specialized rocks are very subtle. The northern zone of the Monkey Hill suite shows the highest SiO_2 content, but all groups overlap in the range 70 to 75 percent SiO_2. The Bayhead granite shows the lowest mean SiO_2 values and the highest CaO, FeO and TiO_2. The Monkey Hill suite shows the lowest FeO content and also significantly lower FeO / FeO + Fe_2O_3 ratios (labelled FERAT), suggesting that it is more oxidized. MgO levels are similar in all units except the Bayhead granite, and uniformly low, showing median values below 0.2 percent. MgO also has a log-normal frequency distribution similar to that of trace elements. The strongly differentiated nature of all three groups is emphasized by comparison with the average for regional granitoid units in Table 2.

Parameters such as the agpaitic index (AGP.I = molecular Na_2O + K_2O / molecular Al_2O_3) and the alumina or I-S ratio (A/CNK = molecular Al_2O_3 / molecular Na_2O + K_2O + CaO) are useful in distinguishing the three suites. None of the suites are wholly peralkaline, but the Lanceground suite and the Cape Strawberry granite both stray into the peralkaline field and show mean agpaitic index values above 0.95. They contrast with granites of the Monkey Hill suite, which are wholly subalkaline and show mean agpaitic index values below 0.9. Agpaitic index values for the Strawberry suite show considerable variation; the Bayhead granite is less agpaitic than other members of the suite.

The A/CNK ratio reveals a complementary grouping. The Monkey Hill suite is mildly peraluminous, with average values in excess of 1.0. The Lanceground suite shows the lowest values ($<.95$), and the Strawberry suite falls between these extremes. These differences are not dramatic, but they characterize the Monkey Hill suite very clearly, and suggest a closer association between the Strawberry and Lanceground suites.

Trace-Element Patterns

Table 2 shows average values for 34 trace elements. The most obvious feature of all groups is relatively high Ba and Sr and relatively low Rb, Li, Be and Pb, especially when compared to Phanerozoic granitoids of equivalent major-element composition (e.g., Tuach *et al.*, 1986). Such features are characteristic of the TLB as a whole and may be a reflection of depleted source materials or a high degree of partial melting in the source region of the batholith. However, Table 2 suggests significant relative enrichment–depletion of some of these parameters between regional and specialized units. Figure 4 shows the distribution (log transformed) of selected elements and ratios that exemplify patterns shown by different groups of trace elements as discussed below.

Patterns for Rb and Sr resemble those for U, Th, Li, Be, Pb and Ba in that they reveal little or no coherent variation or distinction. The Cape Strawberry granite and both areas of the Lanceground suite show low levels of Sr and Ba, which is often considered to be an indication of extreme differentiation. The fluorine content shows a clear distinction between the Monkey Hill suite and the other two suites, which both show mean F contents in excess of 1200 ppm, compared to less than 400 ppm in the Monkey Hill suite. Zr shows a similar contrast, and exemplifies the behaviour of other high-field strength (HFS) elements such as Ga, Nb and Hf, and the rare-earth elements (REE). In addition to separation of the Monkey Hill suite, these elements suggest that the Lanceground suite is enriched significantly in comparison to the Strawberry suite.

Trace-element ratios shown in Figure 4 illustrate patterns displayed by a number of such parameters. The K/Rb ratio, widely used as a differentiation index, shows little or no distinction between the three suites, but is highest (>300) in the Bayhead granite. Lanceground suite granites show slightly higher K/Rb than most Monkey Hill or Strawberry suite granites. Other trace-element ratios used as differentiation indices (e.g., Rb/Sr, Rb/Ba, Y/Ba) show minimal variation and inconsistent patterns, with the exception of Rb/Sr, which is highest in the Lanceground suite, largely as a function of Sr depletion.

La/Ce ratios are close to 0.5 in all components of the TLB, and the three suites show essentially identical mean values, narrow ranges and small standard deviations. The northern zone of the Monkey Hill suite and, to a lesser extent, the Cape Strawberry granite, show asymmetric distributions with high outlying values suggesting disturbance of this relatively constant parameter. The Bayhead granite also shows more variable La/Ce than other units, but appears to have a normal frequency distribution.

F/Zr ratios illustrate the F-enriched nature of the Strawberry suite compared to the other suites, and also show that the enrichment of HFS elements and REE in the Strawberry and Lanceground suites is not proportional to F content. Ga/Al_2O_3 ratios again emphasize contrasts between the Monkey Hill and other suites, and are particularly high in the Lanceground suite. This ratio is commonly used as an indicator of so-called 'A-type' granites (Collins *et al.*, 1982, Whalen *et al.*, 1987), and is accompanied by enrichment in F, Zr and REE.

Figure 5 shows the distribution of several ore and ore-indicator trace elements. Y and Zn show groupings similar to F and Zr, and are signifcantly higher in the Strawberry and Lanceground suites. Data for Sn indicates significant enrichment in these suites relative to the Monkey Hill suite, and also relative to 'average' crustal rocks (typically < 2 ppm).

Mo, Cu and Ta do not show coherent patterns; Mo and Cu data for the Monkey Hill suite and the Cape Strawberry granite are slightly biased by the retention of a few weakly mineralized samples in the database (most were screened out). Median values (Table 2) suggest that these elements are

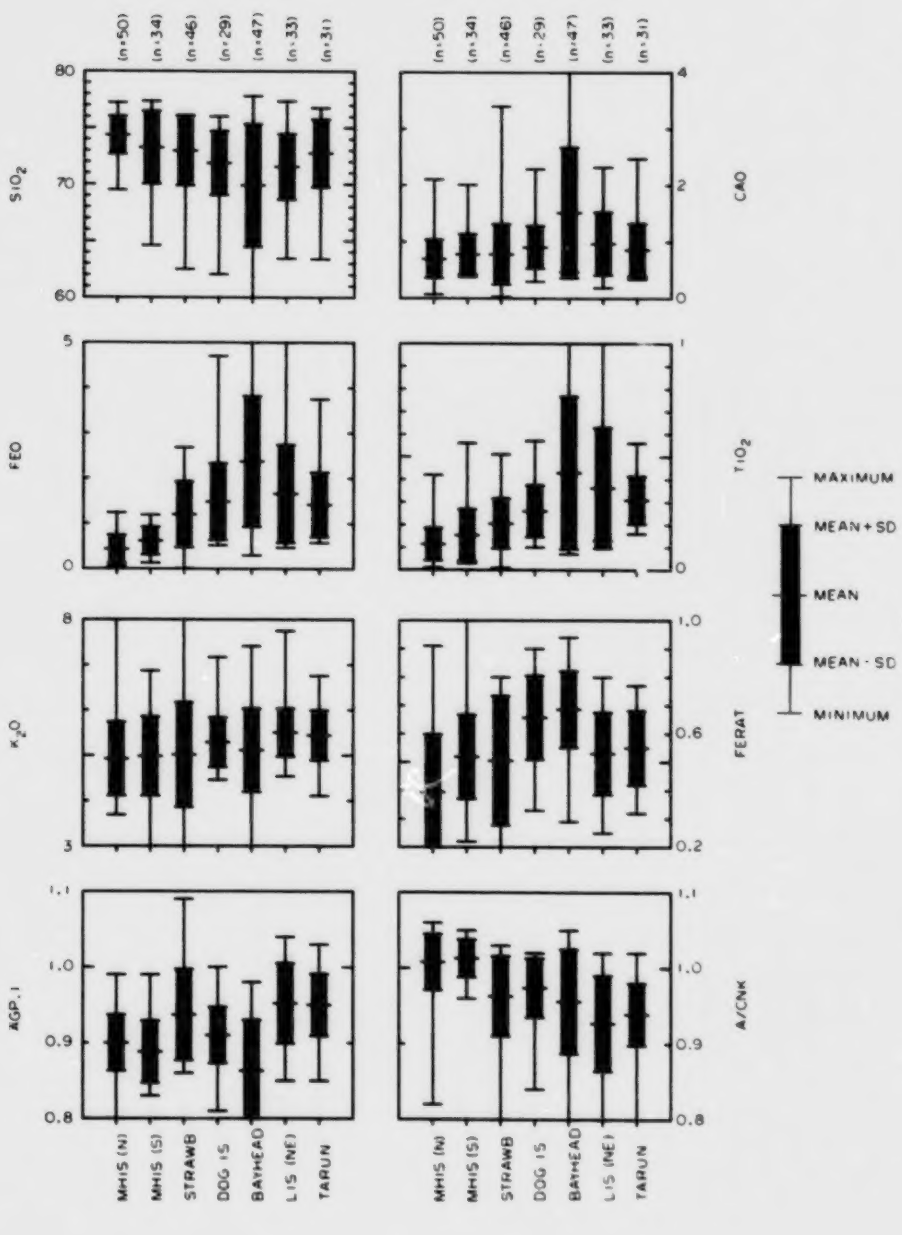


Figure 3. *Distribution of major elements and derived ratios in the three suites of specialized granitoids. MHIS–Monkey Hill intrusive suite; LIS–Lanceground intrusive suite; STRAWB–Cape Strawberry granite; DOG IS. –Dog Island granite; BAYHEAD–Bayhead granite; TARUN–Tarun granite.*

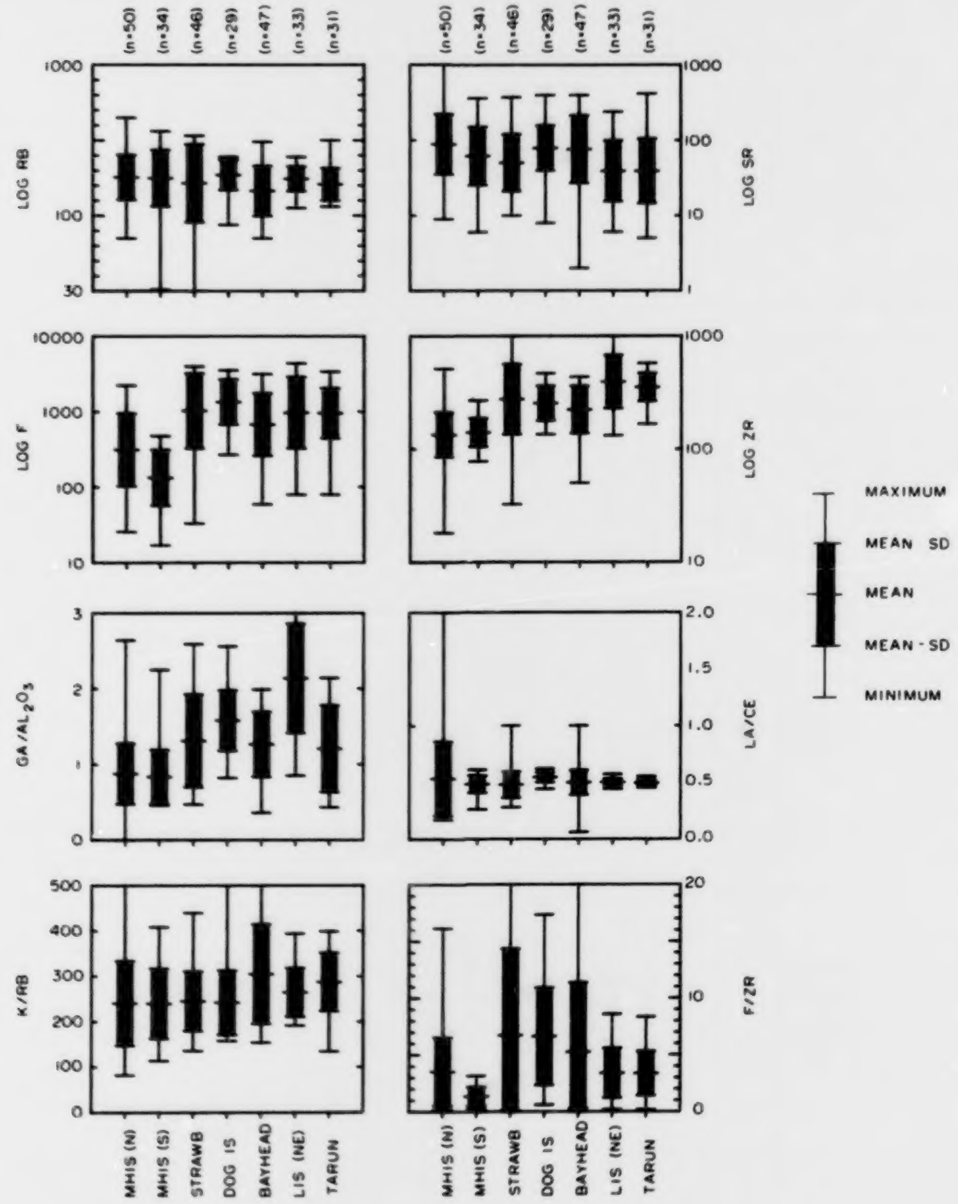


Figure 4. *Distribution of trace elements and derived ratios in the three suites of specialized granitoids. Abbreviations as for Figure 3.*

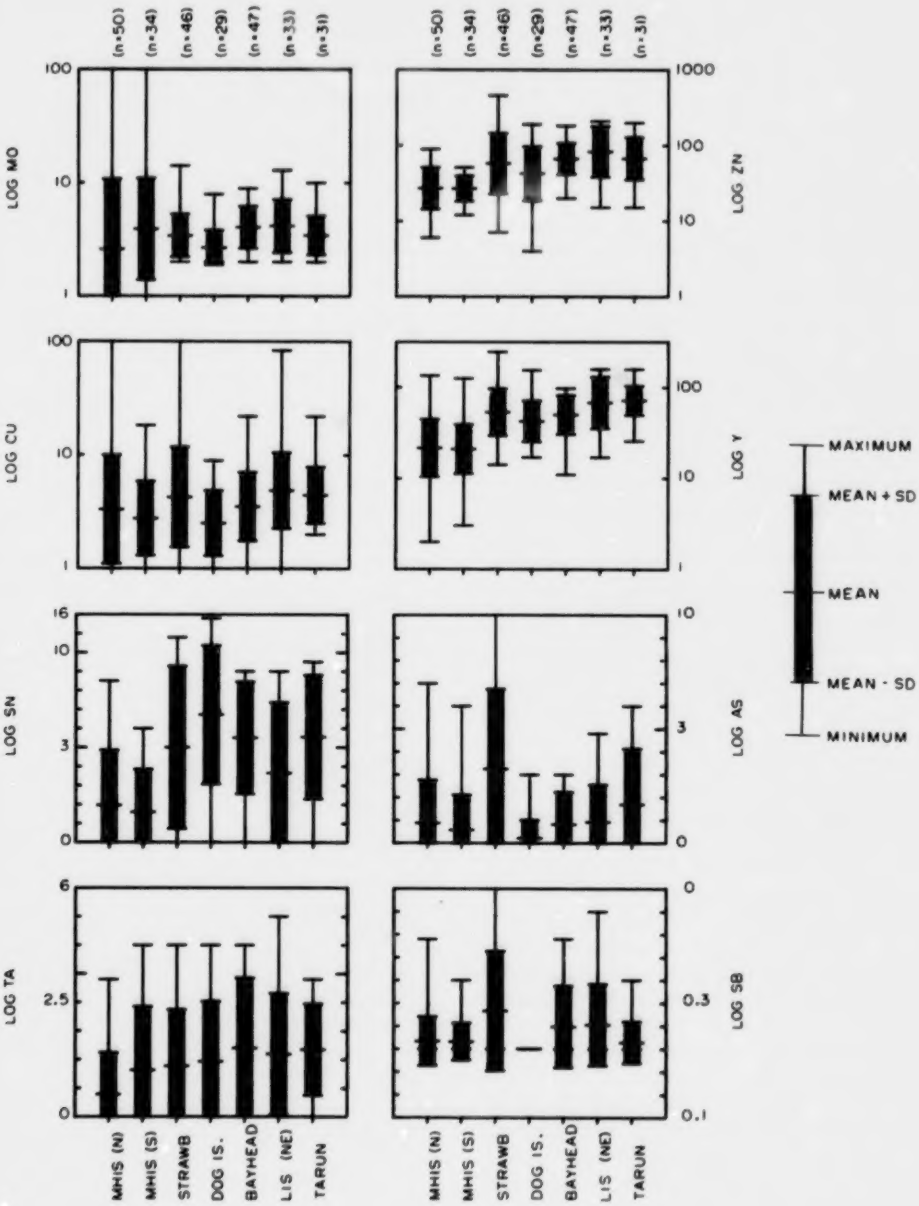


Figure 5. *Distribution of selected 'ore elements' in the three suites of specialized granitoids. Abbreviations as for Figure 3.*

Table 3. Element groupings defined by factor analysis

Factor	Elements Showing Strong Correlation (r > 0.60)	Elements Showing Moderate Correlation (r=0.45-0.60)	Elements Showing Weak Correlation (r=0.30-0.45)
1	Ce, La, Zr, Y, Nb	Mo, Zn, Ga	F
2	U, Th	Rb, Nb, TTDI, Pb	
3	Ba, Sr		
4	Li	F, (-TTDI), Zn	Rb
5	V	Ga	(-TTDI)

Note: Analysis was performed with the FACTOR subprogram of SPSS (Nie *et al.*, 1975) using principal component extraction and varimax rotation.

uniformly low in all groups. Sb and As show little coherent variation but show higher mean values and ranges in the Cape Strawberry granite compared to all other bodies. Median values suggest that this may not be significant, but scattergrams confirm that it is not simply a function of a few high outlying values. Data for W are available, but are almost all at the detection limit (2 ppm), except for a single sample from the Lanceground suite containing 40 ppm.

Table 2 shows that, with the exception of Sn, these elements do not discriminate well between regional and specialized granites in the Trans-Labrador batholith.

Factor Analysis of Trace-Element Data

Factor analysis has been used to clarify patterns and reduce the number of variables required to characterize suites and assess spatial variation within them. This method reduces a large number of variables to a much smaller number of 'factors' (typically < 6) which each represent a group of variables displaying mutually sympathetic or antipathetic behaviour. It was conducted with a subset of data comprising the Thornton-Tuttle Differentiation Index (TTDI−−Sum of normative orthoclase, albite, quartz and feldspathoids) and 20 trace elements for which complete data were available. Trace-element data were log-transformed to compensate for asymmetric frequency distributions, and data for Cr, Ni, Cu and Ag subsequently removed as most values were at or near detection limits. The five-factor model employed explains 72 percent of the variance, and produces the element groupings listed in Table 3. The distributions of Factors 1 to 4 are shown in Figure 6. Factor scores are standardized variables that are expressed in terms of standard deviations. Each has a mean of 0 and a standard deviation of 1.0 for the *entire* population, but significant differences exist between suites.

Factor 1 [Ce, La, Zr, Y, Nb, Mo, Zn, Ga, F]. Factor 1 accounts for almost 30 percent of the total variance. The dominance of this element group comes as no surprise as HFS elements and REE provide the best discriminator of the three suites. All are trace elements whose enrichment is commonly associated with 'alkalic' or 'A-type' tendencies in igneous rocks, and this factor is thus considered to be a measure of such traits. There is no significant correlation with major-element composition, as represented by TTDI.

Factor 1 provides by far the best discrimination of the three suites. Peraluminous Monkey Hill suite granites show negative values compared to positive values for the Lanceground and Strawberry suites. The Lanceground suite has the highest values.

Factor 2 [U, Th, Rb, Pb, Nb, TTDI]. Factor 2 accounts for 18 percent of the total variance and represents a familiar association of large-ion-lithophile (LIL) trace elements and TTDI. In contrast to the HFS element and REE association of Factor 1, it does not provide a good discriminator between suites. However, within individual suites, it should provide a good measure of differentiation, especially when considered in conjunction with Factor 3 (below).

Factor 3 [Ba, Sr]. Factor 3 represents 10 percent of the variance and is confined to two elements that substitute in feldspars and therefore behave as compatible elements in felsic magmas. It can therefore be considered as an inverse measure of differentiation reflecting depletion of Ba and Sr by feldspar fractionation or hydrothermal processes. The Cape Strawberry granite and the Lanceground suite show the lowest values; other units are comparable.

Factor 4 [Li, F, -TTDI, Zn]. The significance of this association, which accounts for 7.5 percent of the variance, is unclear. Zn and F are also part of the Factor 1 association, and TTDI is part of the Factor 2 association. The distribution pattern, however, does not resemble either of these associations. It is highest in the northern zone of the Monkey Hill suite and the Strawberry suite, but reduced in the Lanceground suite. It may reflect variations in the amount of biotite, which concentrates these elements. The slight negative loading with TTDI suggests an association with (relatively) melanocratic rocks.

Factor 5 [V, Ga, -TTDI]. This accounts for only 6.6 percent of the variance, and is of uncertain significance. Ga is part of the Factor 1 association, but V is not present in other associations. The presence of a negative correlation with TTDI suggests that it is primarily a measure of the compatible trace element V, and thus not particularily useful. In four factor models with the same data, V is included with the Factor 3 association.

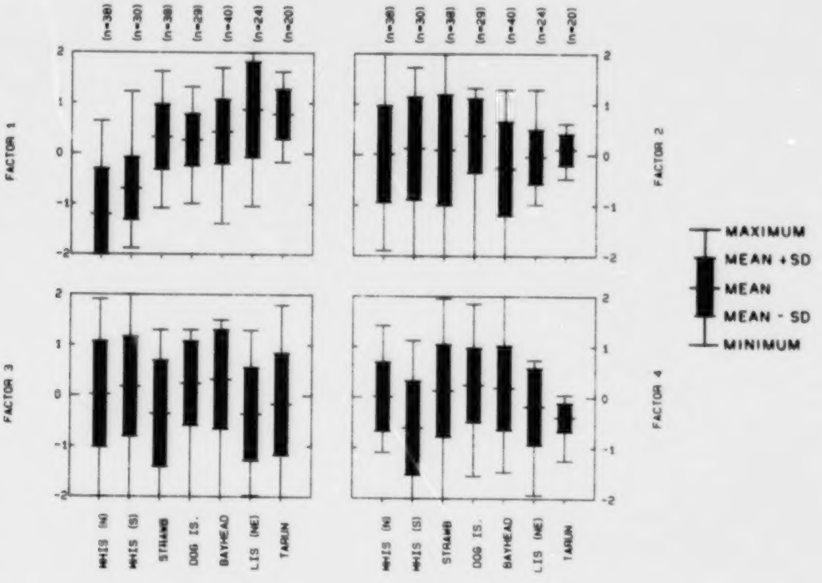


Figure 6. *Distribution of Factors 1 to 4 in the three suites of specialized granitoids. See Table 3 for the element associations represented by each Factor. Abbreviations as for Figure 3.*

SPATIAL GEOCHEMICAL VARIATIONS

An Example from the Strawberry Intrusive Suite

Recognition of geochemical zonation patterns in and around specialized units is an approach that may be valuable in the location of exocontact or near-contact mineralization. Roofward or contactward enrichment of a number of ore elements and indicator trace elements is a feature of many granites associated with mineralization (e.g., Tischendorf, 1977; Ramsay, 1986; Tuach *et al.*, 1986), and commonly culminates at or near ore deposits.

Figure 7 shows the spatial variation of a number of chemical parameters within the Cape Strawberry granite (see Figure 2 for location). This body provides an ideal test case as uniform exposure allows a regular sampling pattern, and a well-defined intrusive contact is present. Samples to the south and east of this contact are mostly from small intrusive bodies (veins, dykes) which may act as 'windows' on the underlying granite. The shape of the contact suggests that the 'roof' of the granite dips southeast and may imply that the entire body has been tilted by later tectonism. This may also be implied by the subvertical attitude of cumulate layering. The exposed area of the granite may thus represent as much as a 3- to 4-km vertical profile through the magma chamber. Contour maps in Figure 7 were prepared by a computer program, and a moderate amount of 'smoothing' has been applied. Visual checks of maps for SiO_2 and Zr against the actual values indicate a good correspondance. Ornamentation patterns reflect values above the 65th percentile (approximately), except for Factor 3, which has been inverted to highlight the lowest values.

Enrichment toward the contact is shown by several elements, such as SiO_2 and U, whereas others (e.g., Mo) show an inverse zonation in which the interior of the body is enriched. The distribution of fluorine is more diffuse, but also suggests contactward enrichment. Variation patterns for trace elements are best summarized by the distributions of Factors 1, 2 and 3 derived from the above analysis.

Factor 1, representing an association of HFS elements and REE, shows strong enrichment toward the contact zone in the northeast of the body, but not toward the southern contact. Minor enrichment is seen in the centre. Examination of single-element distributions for various HFS elements and REE suggests that this may be a hybrid pattern, and that the two groups of elements may behave differently on a local scale. *Factor 2*, representing incompatible LIL elements and major element differentiation, shows very clear enrichment along the southern contact, but lesser enrichment in the northeast. Factor 2 and U distributions are closely similar, but both are subtly different to the SiO_2 pattern, which highlights all areas of the contact. *Factor 3*, representing Ba and Sr, displays an inverse zonation pattern where central parts of the granite are enriched relative to its margins. It is comparable to single-element distributions for Mo and V, and shows some correspondance to Li, which also appears to be depleted near the contact.

An effective measure of *combined* enrichment and depletion is provided by the ratio of *Factor 2* to *Factor 3*, which highlights areas enriched in TTDI, U, Th, Rb, Pb *and* depleted in Ba and Sr. The combined distribution highlights the entire contact zone, but accentuates the northeastern area

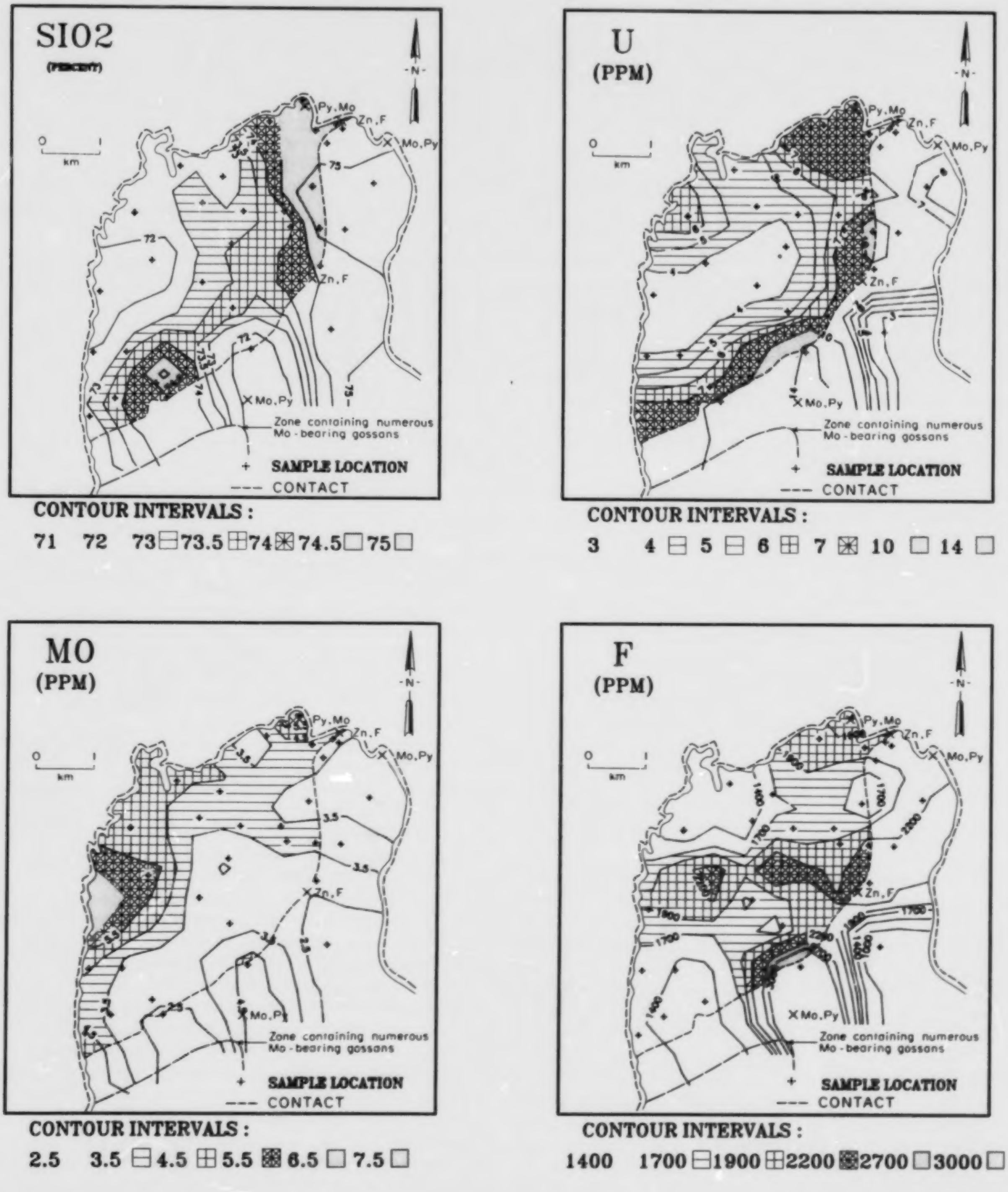

SIO2
(PERCENT)
-N-
0 1
km
Py,Mo
Zn,F
Mo,Py
Zn,F
Mo,Py
72
73
73.5
74
75
Zone containing numerous Mo-bearing gossans
+ SAMPLE LOCATION
--- CONTACT
CONTOUR INTERVALS :
71 72 73 ⊟ 73.5 ⊞ 74 ⊠ 74.5 ☐ 75 ☐
U
(PPM)
-N-
0 1
km
Py,Mo
Zn,F
Mo,Py
Zn,F
Mo,Py
3
4
5
6
7
10
14
Zone containing numerous Mo-bearing gossans
+ SAMPLE LOCATION
--- CONTACT
CONTOUR INTERVALS :
3 4 ⊟ 5 ⊟ 6 ⊞ 7 ⊠ 10 ☐ 14 ☐
MO
(PPM)
-N-
0 1
km
Py,Mo
Zn,F
Mo,Py
Zn,F
Mo,Py
2.5
3.5
4.5
Zone containing numerous Mo-bearing gossans
+ SAMPLE LOCATION
--- CONTACT
CONTOUR INTERVALS :
2.5 3.5 ⊟ 4.5 ⊞ 5.5 ▩ 6.5 ☐ 7.5 ☐
F
(PPM)
-N-
0 1
km
Py,Mo
Zn,F
Mo,Py
Zn,F
Mo,Py
1400
1700
1900
2200
Zone containing numerous Mo-bearing gossans
+ SAMPLE LOCATION
--- CONTACT
CONTOUR INTERVALS :
1400 1700 ⊟ 1900 ⊞ 2200 ▩ 2700 ☐ 3000 ☐

Figure 7. *Spatial distribution of a number of chemical parameters in the Cape Strawberry granite. Contouring performed by the USGS PLOTGEN program with search radius=1500 m, weighting factor=10 and number of nearest neighbours considered=4. For location of this body, refer to Figure 2.*

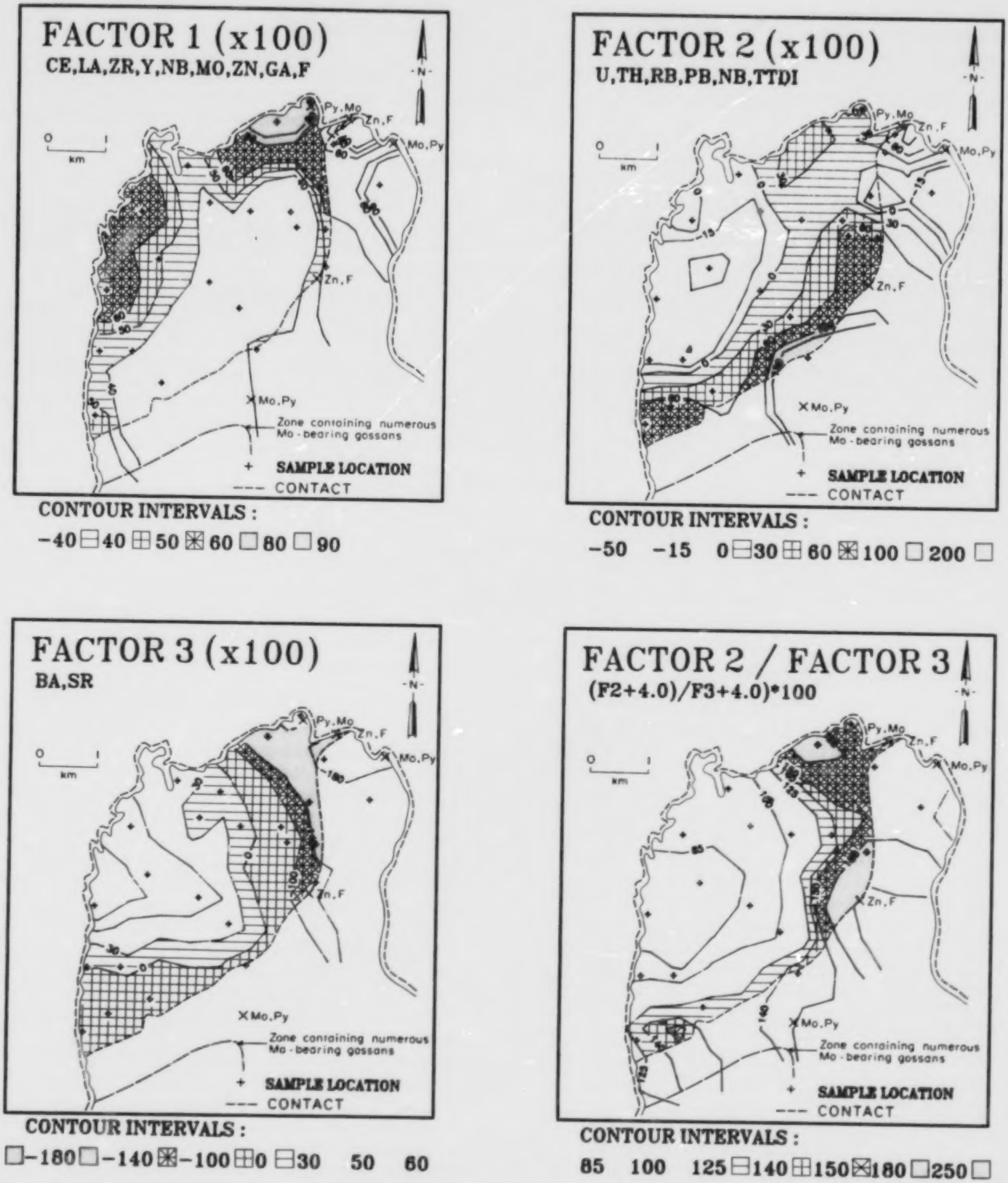

FACTOR 1 (x100)
CE,LA,ZR,Y,NB,MO,ZN,GA,F
-N-
0 1 km
Py,Mo
Zn,F
Mo,Py
Zn,F
Mo,Py
Zone containing numerous Mo-bearing gossans
+ SAMPLE LOCATION
--- CONTACT
CONTOUR INTERVALS :
-40 ⊟ 40 ⊞ 50 ⊠ 60 ☐ 80 ☐ 90
FACTOR 2 (x100)
U,TH,RB,PB,NB,TTDI
-N-
0 1 km
Py,Mo
Zn,F
Mo,Py
Zn,F
Mo,Py
Zone containing numerous Mo-bearing gossans
+ SAMPLE LOCATION
--- CONTACT
CONTOUR INTERVALS :
-50 -15 0 ⊟ 30 ⊞ 60 ⊠ 100 ☐ 200 ☐
FACTOR 3 (x100)
BA,SR
-N-
0 1 km
Py,Mo
Zn,F
Mo,Py
Zn,F
Mo,Py
Zone containing numerous Mo-bearing gossans
+ SAMPLE LOCATION
--- CONTACT
CONTOUR INTERVALS :
☐ -180 ☐ -140 ⊠ -100 ⊞ 0 ⊟ 30 50 60
FACTOR 2 / FACTOR 3
(F2+4.0)/F3+4.0)*100
-N-
0 1 km
Py,Mo
Zn,F
Mo,Py
Zn,F
Mo,Py
Zone containing numerous Mo-bearing gossans
+ SAMPLE LOCATION
--- CONTACT
CONTOUR INTERVALS :
85 100 125 ⊟ 140 ⊞ 150 ⊠ 180 ☐ 250 ☐

Figure 7. *(Continued)*

most strongly, largely due to extreme depletion in Factor 3. Mineralization adjacent to the southwestern contact is associated with a culmination of several trends, and the striking patterns in the northeast suggest that this area may also be worthy of investigation.

SUMMARY AND DISCUSSION

Petrological and geochemical data indicate that specialized granitoid rocks in the TLB can be grouped into three suites. The greatest contrast is between the Monkey Hill suite, consisting of fine grained, peraluminous granite and monzogranite, and the coarse grained metaluminous to slightly peralkaline granites of the Strawberry and Lanceground suites. Trace-element patterns provide a more subtle but consistent contrast between the latter suites. Factor analysis techniques provide the best discriminators between the three suites, and also yield composite variables that are useful measures of 'alkalinity' and 'differentiation' within each. The Cape Strawberry granite shows regular geochemical zonation relative to distance from its outer contact and some geochemical trends highlight areas proximal to known alteration and mineralization.

The following sections of this report discuss the significance of geochemical patterns summarized above, and also the possible affinities of the TLB specialized granites in terms of tectonic setting and economic element associations.

Interpretation of Geochemical Patterns

Major- and trace-element patterns suggest a clear distinction between the Monkey Hill suite and the other suites. The Strawberry and Lanceground suites show some features in common and clearly have a closer chemical affinity. There are, however, some significant differences, the most obvious of which is fluorine content. It has been suggested that HFS element and REE enrichment in A-type and peralkaline granites is largely a function of F enrichment, and Watson (1979) has demonstrated that high F levels enhance the solubility of zirconium in magmas. However, the Lanceground suite shows the highest levels of these elements, but *without* the extreme F enrichment of the Strawberry suite; this contrast is shown well by F/Zr ratios (Figure 4). This suggests that the higher levels of HFS elements and REE in the Lanceground suite are not a function of fluorine enrichment alone. Other features of the suite that suggest a separate origin from the Strawberry suite are common hypersolvus characteristics and spatial association with the Adlavik Intrusive Suite.

It is apparent from Figure 2 that the Monkey Hill and the Strawberry suites coincide in space over a considerable area, whereas the Lanceground suite is geographically distinct from them. Spatial coincidence of two suites showing contrasting compositions could imply that there is a significant age difference between them, and that they represent end-products of two different magmatic lineages. However, available geochronological data suggest very similar K/Ar ages for the two suites, indicating that cooling and hydrothermal activity were contemporaneous, at least in the north (Gower *et al.*, 1982).

These data suggest an alternative interpretation, namely that the Monkey Hill and Strawberry suites are variants or derivatives of a single magma, and observed differences in composition reflect late-stage processes such as hydrothermal activity in the roof zone of the magma chamber. The contrasting fluorine contents of the two suites could reflect loss of fluorine from the Monkey Hill suite, as suggested by Bailey (1977) for some fluorine-enriched magmas. The presence of fluorite and zircon in some veins associated with the Round Pond granite (MacDougall and Wilton, 1987; MacDougall, personal communication) may indicate some loss of F and Zr. Deuteric effects within Monkey Hill suite granites are indicated by chloritization of biotite, and also by disturbance of the La/Ce ratio (Figure 4). The principal argument against this interpretation is that transitional rock types are not present, and that (aside from chlorite) petrographic evidence for pervasive alteration of Monkey Hill suite granites is not present in the main body, which has a composition closely comparable to that of the mineralized Round Pond granite. Igneous textures are well preserved for the most part, and the remarkable homogeneity of the main body over almost a kilometer of vertical relief argues against any progressive alteration in the roof zone of this magma chamber. Preliminary analysis suggests that cryptic trace-element zonation is also absent.

In contrast, the Cape Strawberry granite shows a disorganized trace-element pattern suggesting redistribution of mobile elements, and also displays regular chemical zonation suggesting the concentration of silica and lithophile elements toward the upper or sidewall contact. A similar zonation pattern was suggested by MacKenzie and Wilton (1987) in the Burnt Lake granite, where it culminates near endocontact molybdenum mineralization. Patterns of this type appear to be characteristic of high-silica and specialized granitoid systems, and have been recognized *in situ* (Ackley granite; Tuach *et al.*, 1986) and in eruptive products (Hildreth, 1981). The Cape Strawberry body is small compared to these examples, but is simply a protrusion on the upper surface of a body with comparable overall dimensions. Zonation may reflect a number of processes, including fractional crystallization and liquid-state mechanisms such as convective fractionation or volatile fluxing. The high fluorine content of the Strawberry suite granites would act to reduce viscosity and enhance liquid-state fractionation (Dingwell, 1985) and also provide a volatile phase that could complex and transport elements.

At the present time, the preferred interpretation is that all three suites represent magmas of separate origin, and that there may be an age difference between the Monkey Hill and Strawberry suites. Zircon and/or sphene U–Pb dating would help to resolve this problem, and is currently underway.

Identification of Precursor Suites

'Precursor granites' are bodies that are spatially associated with and may precede metallogenetically specialized granites (Tischendorf, 1977) The spatial association between the Lanceground intrusive suite and the Adlavik Intrusive Suite suggests that it may represent the end product of this lineage. Parts of the Lanceground suite are compositionally and texturally similar to syenites of the Adlavik Intrusive Suite. A mineralogical link is provided by the presence of relict fayalite in the Lanceground Suite, which is also a component of Adlavik syenites. These syenites also show moderately high Zr, Y, La and Ce contents.

There is no obvious spatial association between members of the Strawberry suite and any one regional granitoid unit. However, geochemical data suggest that the Bayhead granite or similar rocks may have been precursors to the more highly differentiated Cape Strawberry and Dog Island granites. It is consistently less evolved yet displays strong mineralogical and textural similarities. The principal difference between the Bayhead granite and other members of the suite is level of exposure. The geochemical differences suggest vertical zonation within Strawberry suite magma chambers, and imply that in this case the 'precursor' may simply be a portion of an equivalent magma chamber below compositionally stratified levels represented by the Cape Strawberry unit.

Assigning precursor units for the Monkey Hill suite is more difficult as there are no regionally extensive peraluminous granitoid rocks within the area. The most comparable unit is the Crooked River granite of Ryan (1985), which is well removed geographically from the Monkey Hill suite.

Affinities and Mineral Potential of TLB Specialized Granitoid Rocks

Figure 8 shows discrimination diagrams commonly employed in the study of granitoid rocks, with broad fields for the three specialized suites, regional granitoid units and the Adlavik Intrusive Suite.

The K_2O vs Na_2O diagram illustrates the similarity of major-element compositions; the three specialized suites occupy essentially identical fields. Regional granitoid units show a tendency to higher soda, which is also echoed by the Bayhead granite of the Strawberry suite. All three groups plot along the upper edge of the A-type granite field defined by White and Chappel (1983). Ga vs Al_2O_3 shows a clearer separation, with higher Ga and Ga/Al ratios displayed by the Strawberry and Lanceground suites, and a restricted low-Ga field for the Monkey Hill suite. Strawberry and Lanceground suite granites are A-type granites in this plot, whereas the Monkey Hill suite lies in the field of I- and S-type granites. The (Y+Nb) vs Rb plot (Pearce *et al.*, 1984) places the Monkey Hill suite in the volcanic arc and syn-collisional field, and the Strawberry and Lanceground suites in the field of within-plate granites. Regional granitoid units and the Adlavik Intrusive Suite are equally distributed between these fields and that of volcanic-arc granites. Ti/Zr vs Nb/Y, commonly used in the classification of felsic volcanic rocks (Winchester and Floyd, 1977), shows a smooth trend from the Adlavik Intrusive Suite to regional granitoid units, and then divergence amongst the three specialized suites. The Strawberry intrusive suite has the most variable composition, and strays into the field occupied by peralkaline volcanic rocks such as comendite and pantellerite.

The results of this study suggest an empirical similarity between the Strawberry and Lanceground suites and A-type, anorogenic or within-plate granites, and between the Monkey Hill suite and volcanic-arc or syn-collisional granites. It seems unlikely that the two groupings represent radically different tectonic environments as they seem to be of broadly similar age. The contrasts in affinity may instead be a reflection of different source materials within the crust.

From an economic point of view, A-type granitoid rocks are associated with Pb−Zn, Sn, Nb−Ta, U, F and, in strongly peralkaline variants, with Zr−Y−REE deposits. Sn data for the Strawberry suite is clearly anomalous relative to average crust, and these granites may have some potential for tin in addition to known potential for Mo, Cu, Pb and Zn. The Lanceground suite is the most enriched in Zr, Y and REE, but falls well short of levels in peralkaline intrusives elsewhere in Labrador (Miller, *this volume)*. However, values of up to 2400 ppm Zr and 160 ppm Y in a dyke assigned to the Lanceground Suite are of interest. Biotite-rich cumulate zones in Strawberry suite granites contain up to 2400 ppm Zr, 400 ppm Y and 2300 ppm Ce.

Monkey Hill suite granites are not S-type granites in the strict sense of the term (Chappel and White, 1974), but have peraluminous traits. They resemble 'plumasitic' specialized granites associated with Sn−W−Ta−F mineralization from the Arabian shield (Ramsay, 1986), but have lower F. There is some evidence of tungsten (up to 160 ppm) in the Round Pond vein swarm, and potential might exist for tungsten-bearing skarns in addition to molybdenum and copper. There is, however, no sign of tin or tungsten enrichment in Monkey Hill suite granites.

Mineral Potential of Individual Bodies

The highest potential lies in rocks with known mineralization including the Cape Strawberry granite (Strawberry intrusive suite), the Round Pond granite and Burnt Lake granite (Monkey Hill intrusive suite). The exocontact nature of mineralization suggests that first priority should be given to those plutons that have well-defined intrusive contacts with their host rocks, and in which geochemical zonation patterns indicate significant mass transport of incompatible elements. Culminations of geochemical trends similar to those illustrated in Figure 7 provide the best indication of promising areas. In addition to the established targets listed above, the Dog Island granite and Pistol Lake granite may have potential. The Monkey Hill suite includes a number of small cupolas and stocks that have not been explored. The area around the Duck Island granite lies above one that contains endocontact molybdenum, and is worth further investigation.

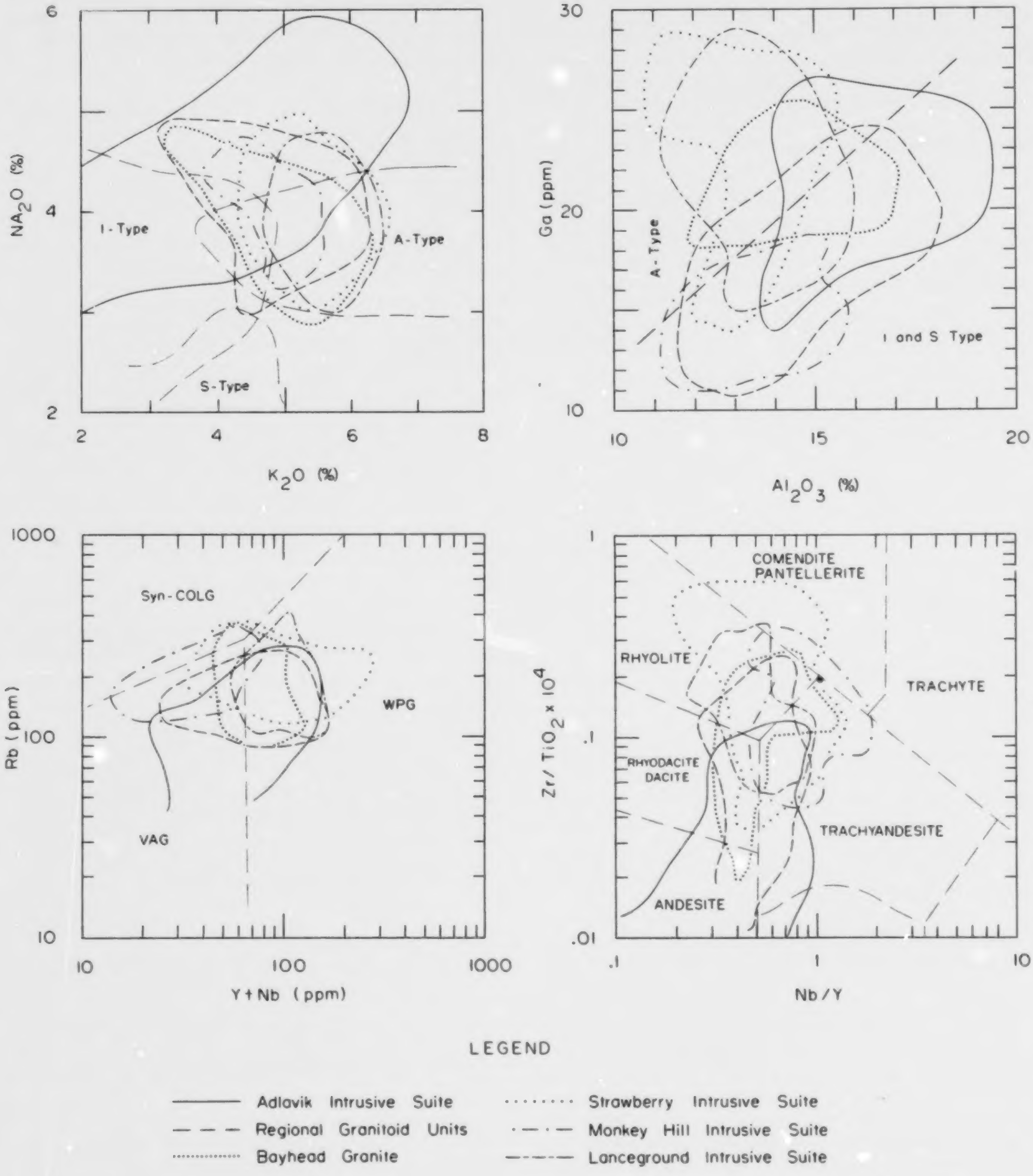


Figure 8. *Selected major and trace-element discrimination plots. Field boundaries from Pearce* et al. *(1984), White and Chappel (1983), Winchester and Floyd (1977), and Collins* et al.*, 1982.*

ACKNOWLEDGMENTS

Data collection and field work for this project has been greatly aided by the efforts of assistants over three years. Particular thanks are extended to Gerry Squires and Hamish Sandeman, who provided competent and enthusiastic work in 1985 and 1986 respectively. Thanks are also extended to Janet Russell, who helped with field work in 1987, and also endured a lot of computer-related tedium. Wayne Tuttle and Ken O'Quinn provided their usual competent logistical support in Goose Bay. Field work in the Makkovik area was aided greatly by numerous members of the Andersen family. I wish to thank Anders and Bridget, and also Bob ('Coon') and Fiona for their assistance, friendship and hospitality, and most of all for allowing me to use their scenic and idyllic fishing station at Lanceground in 1985 and 1987. Naming a stratigraphic unit after it is the least I can do! This manuscript was greatly improved by a merciless critical review by John Tuach, and by comments from Peter Davenport, Dick Wardle and Derek Wilton.

REFERENCES

Bailey, D.G.
1979: The geology of the Walker Lake–MacLean Lake area, Central Mineral Belt, Labrador. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 1-8.

Bailey, J.C.
1977: Fluorine in granitic rocks and melts: A review. Chemical Geology, Volume 19, pages 1-42.

Chappell, B.W. and White, A.J.R.
1974: Two contrasting granite types. Pacific Geology, Volume 8, pages 173-174.

Collins, W.J., Beams, S.D. and White, A.J.R.
1981: Nature and origin of A-type granites with particular reference to S.E. Australia. Contributuions to Mineralogy and Petrology, Volume 80, pages 189-200.

Dickson, W.L.
1983: Geology, geochemistry and mineral potential of the Ackley granite and parts of the Northwest Brook and Eastern Meelpaeg Complexes, southeast Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-6, 129 pages.

Dingwell, D.B.
1985: The structure and properties of F-rich silicate melts: implications for granite petrogenesis. *In* Granite-related Mineral Deposits. *Edited by* R.P. Taylor and D.F. Strong. CIM Geology Division, pages 72-82.

Gower, C.F.
1981: The geology of the Benedict Mountains, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-3, 26 pages.

Gower, C.F., Flanagan, M.J., Kerr, A. and Bailey, D.G.
1982: Geology of the Kaipokok Bay–Big River Area, Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-7, 77 pages.

Gower, C.F. and Ryan, A.B.
1986: Proterozoic evolution of the Grenville Province and adjacent Makkovik Province in eastern and central Labrador. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A.J. Baer. Geological Association of Canada, Special Paper 31, pages 281-296.

Hildreth, E.W.
1981: Gradients in silicic magma chambers: implications for lithospheric magmatism. Journal of Geophysical Research, Volume 86, pages 10153-10192.

Kerr, A.
1986: Plutonic rocks of the eastern Central Mineral Belt, Labrador: General geology and description of regional granitoid units. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 89-100.

1987a: Plutonic rocks of the eastern Central Mineral Belt: Lithogeochemical patterns and the identification of potential specialized granitoids. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 161-181.

1987b: Geochemistry and mineral potential of evolved granitoid rocks and layered mafic intrusions within the Trans-Labrador batholith, eastern Labrador. *In* Report of Activities. Newfoundland Department of Mines, Mineral Development Division, pages 39-42.

In preparation: Geochemical data from granitoid rocks of the Makkovikian and Trans-Labrador batholiths, eastern Central Mineral Belt, Labrador. Newfoundland Department of Mines, Mineral Development Division, Open File.

MacDougall, C.S.
In preparation: Granite-related mineralization in the Round Pond area, Makkovik Province, eastern Labrador. M.Sc Thesis. Memorial University of Newfoundland.

MacDougall, C.S. and Wilton, D.H.
1987: Middle Proterozoic granite-related mineralization in the Round Pond area, Labrador. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 457-466.

MacKenzie, L.M. and Wilton, D.H.C.
1987: Uranium, molybdenum and base metal sulphide mineralization in the Burnt Lake area, central Labrador; three different styles of ore formation. *In* Current Research, part A. Geological Survey of Canada, Paper 87-1A, pages 467-477.

Miller, R.R.
This volume: Yttrium (Y) and other rare metals (Be, Nb, REE, Ta, Zr) in Labrador.

Nie, N.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K. and Bent, D.H.
1975: SPSS. Statistical package for the social sciences. Second Edition, McGraw-Hill, 675 pages.

Pearce, J.A., Harris, N.B.W. and Tindle, A.G.
1984: Trace element discrimination diagrams for the tectonic interpretation of granitoid rocks. Journal of Petrology, Volume 25, pages 956-983.

Ramsay, C.R.
1986: Specialized felsic plutonic rocks of the Arabian Shield and their precursors. Journal of African Earth Sciences, Volume 4, pages 153-168.

Ryan, A.B.
1985: Regional geology of the central part of the Central Mineral belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Memoir 3, 185 pages.

Taylor, R.P. and Strong, D.F.
1985: Granite-related mineral deposits: Geology, petrogenesis and tectonic setting. Extended Abstracts of papers presented at the CIM conference in Halifax, 1985 CIM Geology Division.

Tischendorf, G.
1977: Geochemical and petrographic characteristics of silicic magmatic rocks associated with acid magmatism. *In* Metallization Associated with Acid Magmatism. *Edited by* M. Stemprok. Geological Survey of Czechoslovakia, pages 41-96.

Tuach, J., Davenport, P.H., Dickson, W.L. and Strong, D.F.
1986: Geochemical trends in the Ackley granite, southeast Newfoundland: Their relevance to magmatic/metallogenic processes in high-silica granitoid systems. Canadian Journal of Earth Sciences, Volume 23, pages 747-765.

Wardle, R.J. Rivers, T., Gower C.F., Nunn, G.A.G. and Thomas, A.
1986: The northeastern Grenville Province: new insights. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A.J. Baer. Geological Association of Canada, Special Paper 31, pages 13-31.

Watson, E.B.
1979: Zircon saturation in felsic liquids: experimental results and applications to trace element geochemistry. Contributons to Mineralogy and Petrology, Volume 70, pages 407-419.

Whalen, J.B., Currie, K.L. and Chappel, B.W.
1987: A-type granites: geochemical characteristics, discrimination and petrogenesis. Contributons to Mineralogy and Petrology, Volume 95, pages 407-419.

White, A.J.R. and Chappel, B.W.
1983: Granitoid types and their distribution in the Lachlan Fold Belt, Southeastern Australia. Geological Society of America, Memoir 159, pages 21-34.

Wilton, D.H.C. and Wardle, R.J.
1987: Two contrasting metallogenic styles in the early Proterozoic Upper Aillik Group, Central Mineral Belt, Labrador, Canada. Mineralium Deposita, Volume 22, pages 198-206.

Wilton, D.H.C., MacDougall, C.M. and MacKenzie, L.M.
1986: Final report on 1985 field work in the Central Mineral Belt of Labrador. Geological Survey of Canada Internal Report, 149 pages.

Wilton, D.H.C., MacDougall, C.M., MacKenzie, L.M. and North, I.N.
1987: Final report on 1986 field work in the Central Mineral Belt of Labrador. Geological Survey of Canada Internal Report, 121 pages.

Winchester, J.A. and Floyd, P.A.
1977: Geochemical distinction of different magma series and their differentiation products, using immobile elements. Chemical Geology. Volume 20, pages 325-313

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 37-48

AN INVESTIGATION OF THE MARGIN OF THE LAC JOSEPH ALLOCHTHON, GRENVILLE PROVINCE, SOUTHWESTERN LABRADOR

J.N. Connelly
Labrador Mapping Section

ABSTRACT

Mapping in 1987 was directed toward examining the boundary zone between the Lac Joseph allochthon and the stucturally underlying parautochthonous terrane of southwestern Labrador, and investigating an area around Lac Joseph within the allochthon proper. Mylonites derived from rocks in both the allochthonous and parautochthonous terranes were documented along the boundary zone, which separates the upper-amphibolite- to granulite-facies Lac Joseph allochthon (composed of polydeformed 1650 Ma, two-leucosome paragneisses and younger megacrystic granite and gabbronorite) from the greenschist- to upper-amphibolite-facies parautochthon (comprising metasediments of the Knob Lake Group, which contain a single leucosome in the areas of highest metamorphic grade, and which are intruded by gabbros and equigranular granite). Scarce kinematic indicators suggest that the allochthon was emplaced toward the north to northwest over the parautochthon. North of the Lac Joseph allochthon, an intrusive domain within the parautochthon has been identified; it is thought to be separated from the predominantly metasedimentary domain to the north by an intraparautochthon thrust.

In the Lac Joseph area, gabbros of the Shabogamo Intrusive Suite are bounded by high strain zones that form the contact with the surrounding allochthonous gneisses. These rocks are interpreted to be part of the parautochthonous terrane exposed in a structural window through the overlying Lac Joseph allochthon. Extensive retrogression of the mafic gneiss along the contact may be attributed to upward fluid migration during or after emplacement of the allochthon. Although critical radiometric dates are lacking, a model, consistent with available data, involves emplacement of the ca. 1650 Ma allochthon gneiss terrane onto the parautochthon (which was shortened internally by thrusting and folding) during the Grenvillian Orogeny.

INTRODUCTION

Recent work in southwestern Labrador has resulted in identification of a number of terranes within the Grenville Province that are thought to be parautochthonous and allochthonous relative to the Churchill and Superior foreland to the north and northwest of the Grenville Front (Rivers, 1983a; Nunn *et al.*, 1984; Rivers and Nunn, 1985; Rivers and Chown, 1986; Wardle *et al.*, 1986; and Thomas *et al.*, 1985) (Figure 1). These terranes were recognized through regional mapping and the subsequent realization that significant lithological, structural and metamorphic contrasts existed between terranes within this part of the Grenville Province. Aeromagnetic patterns were of use in the definition of the terrane boundaries. Radiometric investigations further revealed that gneisses within the allochthonous terranes, which were previously thought to have formed during the Grenvillian Orogeny, had developed during a previously unrecognized ca. 1650 Ma thermotectonic event termed the Labradorian Orogeny by Nunn *et al.* (1984), Nunn *et al.* (1985) and Thomas *et al.* (1985). The effects of the Grenvillian thermotectonism on the allochthons, if any, are still not understood. The 1650 Ma gneiss terranes are distinct from the parautochthonous and autochthonous terranes to the north and west in that, the latter two terranes, are thought to have been affected mainly by the Grenvillian Orogeny. In spite of regional mapping that has led to the identification of these terranes, there have been no detailed studies along the terrane boundaries.

During the 1987 field season, the author examined the boundary zone between the allochthonous Lac Joseph terrane and the underlying parautochthon in western Labrador, and compared rock types and the structural and metamorphic histories within each terrane. Four areas (labeled A–D in Figure 2) were selected along the boundary, as defined previously by regional mapping (Rivers, 1985a,b,c; Nunn and Christopher, 1987; and Wardle, 1982), where the exposure was sufficient to warrant a more detailed examination of the contact zone and the rock types on either side. Work within Area E (Figure 2) around Lac Joseph was performed in an attempt to explain the diminished aeromagnetic signature in the central part of the Lac Joseph allochthon.

REGIONAL GEOLOGY

The autochthon immediately to the north of the Grenville Front constitutes the southerly extension of the metasedimentary foreland of the Superior and Churchill provinces (Figure 1). Metasediments within the autochthon

---

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

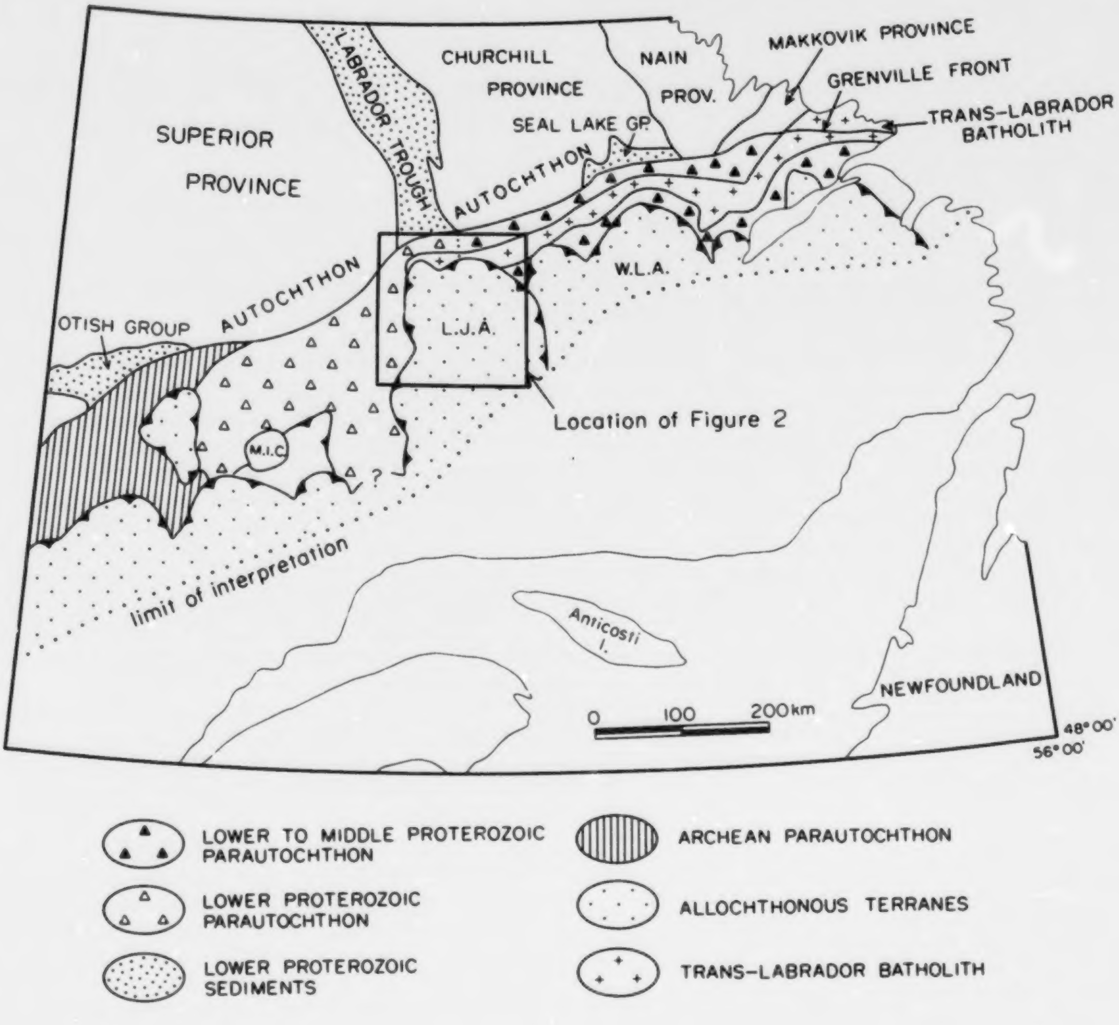

SUPERIOR PROVINCE
LABRADOR TROUGH
CHURCHILL PROVINCE
NAIN PROV.
MAKKOVIK PROVINCE
GRENVILLE FRONT
TRANS-LABRADOR BATHOLITH
SEAL LAKE GP.
AUTOCHTHON
AUTOCHTHON
OTISH GROUP
W.L.A.
L.J.A.
M.I.C.
?
Location of Figure 2
limit of interpretation
Anticosti I.
NEWFOUNDLAND
0
100
200km
48°00'
56°00'
LOWER TO MIDDLE PROTEROZOIC PARAUTOCHTHON
LOWER PROTEROZOIC PARAUTOCHTHON
LOWER PROTEROZOIC SEDIMENTS
ARCHEAN PARAUTOCHTHON
ALLOCHTHONOUS TERRANES
TRANS-LABRADOR BATHOLITH

Figure 1. *Tectonic subdivisions of the Grenville Orogen in Labrador and Quebec. Lithological units that can be traced from autochthon to parautochthon are shown. L.J.A.–Lac Joseph allochthon (from Rivers and Chown, 1986); M.I.C.–Manicouagan Impact Crater; W.L.A–Wilson Lake allochthon.*

belong to the Kaniapiskau Supergroup of the Labrador Trough. These rocks are principally represented in the study area by the lower Knob Lake Group, a predominantly clastic and carbonate sequence with minor amounts of metavolcanic rocks. These metasediments have been intruded by the 1375 Ma gabbroic Shabogamo Intrusive Suite (Brooks *et al.*, 1981; Zindler *et al.*, 1981 and Dallmeyer, 1982).

The transition from autochthon to parautochthon toward the southeast is marked by the first significant thrust fault or major ductile shear zone (Rivers and Chown, 1986). The parautochthon, like the autochthon, is composed of rocks of the Knob Lake Group, middle Proterozoic granitic and basic intrusive rocks and minor sillimanite-bearing paragneiss. Metamorphic rocks within the parautochthon west of Ossokmanuan Lake (Figure 2), within the Gagnon terrane (Rivers *et al.*, *in press*), are thought to have obtained their tectonometamorphic imprint during the Grenville Orogeny. Within the parautochthon east of Ossokmanuan Lake (Churchill Falls terrane), sillimanite-bearing paragneiss is cut by Trans-Labrador batholith granite which is subsequently metamorphosed, indicating plutonism and metamorphism during both the Labradorian and Grenvillian orogenies. Grenvillian metamorphism within the parautochthon reached upper-amphibolite-grade conditions (Rivers and Chown, 1986).

The allochthonous terranes comprise Labradorian (ca. 1650 Ma) amphibolite- to granulite-facies paragneisses and younger basic and acid plutonic rocks. Models have been proposed (Nunn *et al.*, 1985; Rivers and Chown, 1986) in which it is envisaged that these terranes were emplaced on top of the telescoped parautochthonous terrane during the Grenvillian Orogeny. However, the concordant nature of the ca. 1650 Ma U–Pb dates from within the allochthon implies that the allochthons did not undergo extensive thermal reworking during the Grenvillian Orogeny (Nunn *et al.*, 1985).

RESULTS

Area A: Wabush–Ross Bay Junction

Previous work in this area by Rivers (1985b) resulted in the separation of a middle- to upper-amphibolite-facies metasedimentary terrane intruded by gabbroic and granitic rocks east of Labrador City (in the parautochthon) from an upper-amphibolite- to granulite-facies paragneiss–gabbro–granite terrane to the east (the Lac Joseph allochthon). A 50-km transect in this area between Labrador City–Wabush and Ross Bay Junction (Figure 2) was chosen because of the known occurrence of mylonites near the boundary between these terranes (T. Rivers, personal communication). Exposure within the boundary zone is patchy.

The two terranes within this area are lithologically, metamorphically, and, to a lesser extent, structurally distinct. Three significant lithological differences were observed:

1) granites within the allochthon tend to be megacrystic and may contain orthopyroxene whereas the parautochthonous granites are equigranular, muscovitic and biotitic, and are typically strongly foliated (Plate 1);

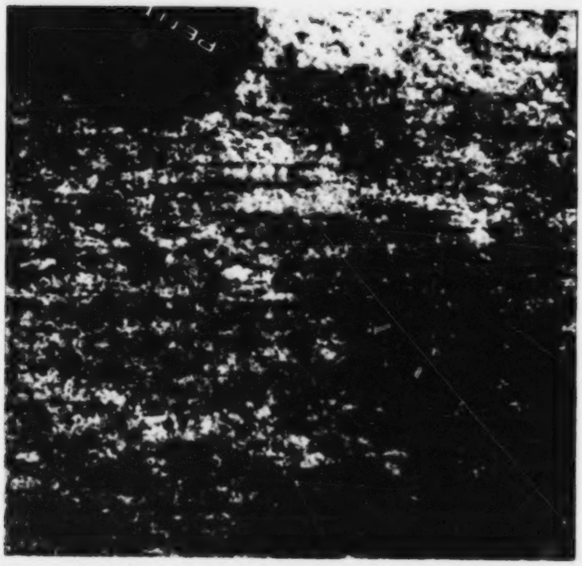


Plate 1. *Strongly-foliated, biotite granite from the parautochthon east of Wabush–Labrador City*

2) gabbros in the allochthon are typically extensively recrystallized and equigranular, but may be coarse grained to pegmatitic with primary igneous textures (Plate 2); the gabbros in the parautochthon are equigranular, variably deformed, garnet bearing and commonly exhibit corona textures (Plate 3); and

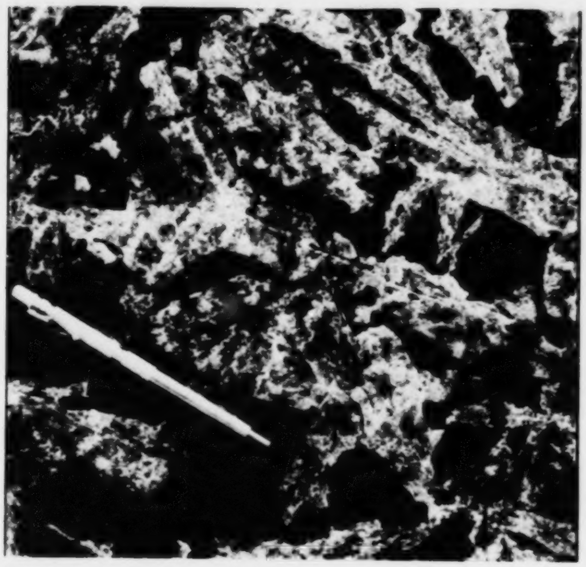


Plate 2. *Coarse grained gabbronorite from the Lac Joseph allochthon east of Ross Bay Junction.*

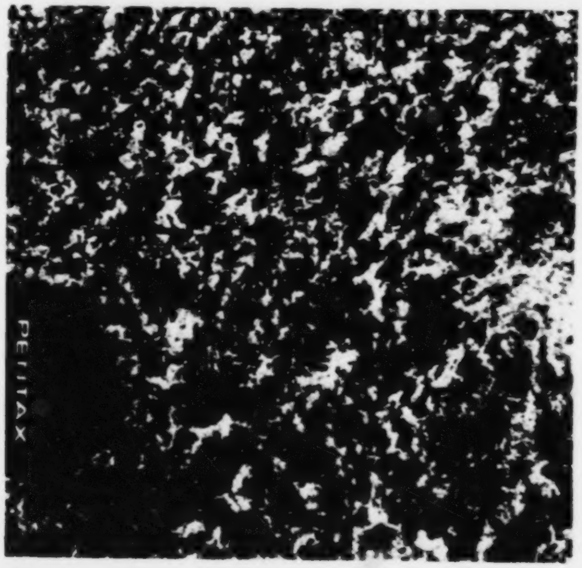


Plate 3. *Garnet-coronatic gabbro of the Shabogamo Intrusive Suite within the parautochthon east of Wabush–Labrador City.*

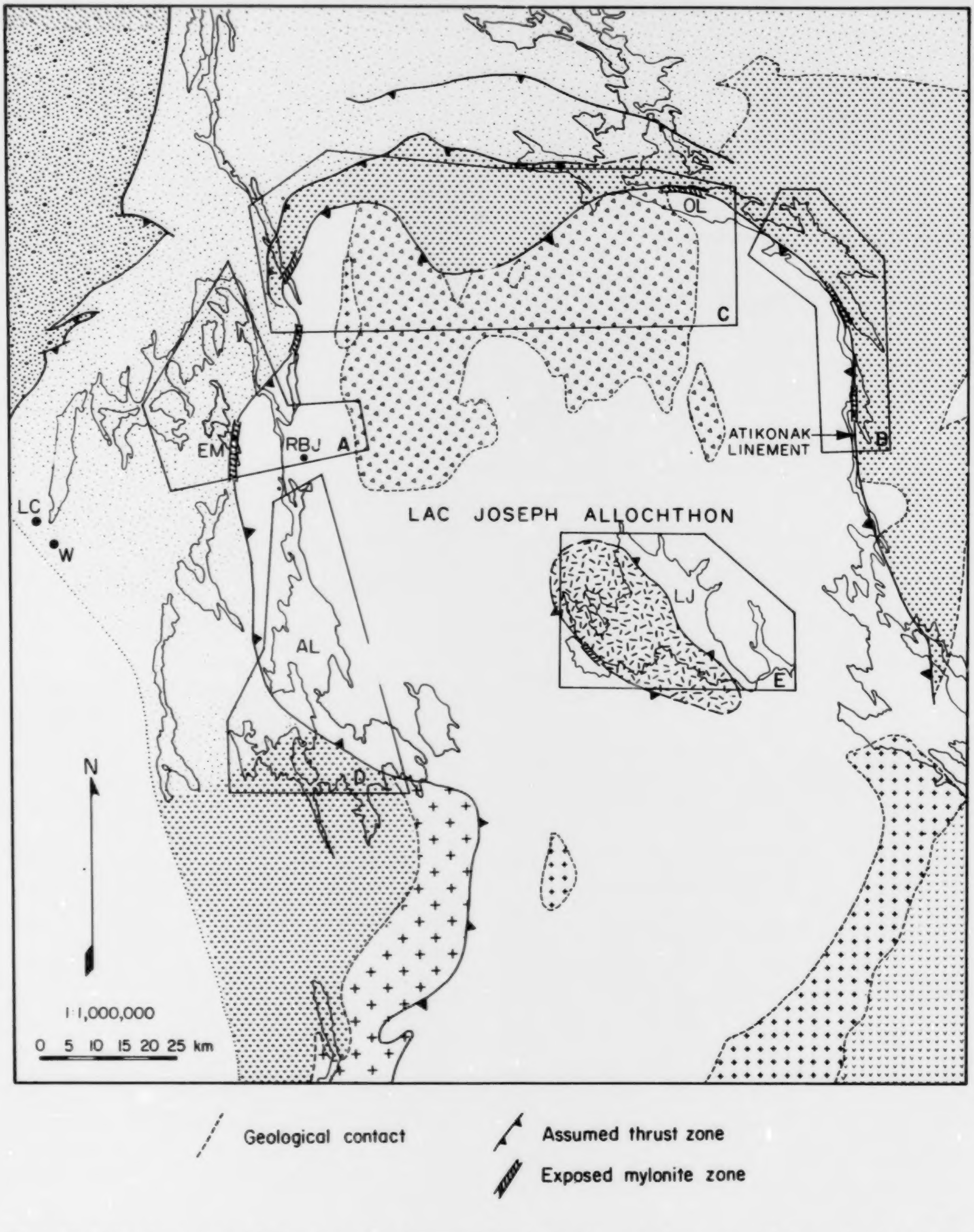

OL
C
B
ATIKONAK LINEMENT
EM
RBJ
A
LC
W
LAC JOSEPH ALLOCHTHON
LJ
E
AL
D
N
1:1,000,000
0 5 10 15 20 25 km
Geological contact
Assumed thrust zone
Exposed mylonite zone

Figure 2. *Map showing simplified geology of southwestern Labrador and location of map areas labeled A–E. AL–Ashuanipi Lake; LE–Lac Emerillon; LC–Labrador City; LJ–Lac Joseph; OL–Ossokmanuan Lake; RBJ–Ross Bay Junction; W–Wabush. For location of map area see Figure 1.*

LEGEND

PARAUTOCHTHON

⊕ *Granite; equiqranular, weak- to moderately-foliated*

▨ Shabogamo Intrusive Suite: *partially recrystallized and foliated gabbro with garnet corona texture*

▨ *Mixed granite, granodiorite, granitic orthogneiss and Shabogamo Intrusive Suite*

▨ Knob Lake Group: *pelitic metasediments, locally partially melted; intruded by Shabogamo Intrusive Suite and lesser amounts of granite*

LAC JOSEPH ALLOCHTHON

▨ *Granite; megacrystic and rapakivi-textured granite*

▨ *Anorthosite*

▨ *Gabbronorite to gabbro; recrystallized, locally foliated, fine to medium grained*

○ *Pelitic paragneiss; typically sillimanite-bearing restite interlayered with K-feldspar–plagioclase–quartz leucosome; interlayered with mafic gneiss and locally intruded by equigranular granite and gabbronorite*

SUPERIOR PROVINCE

▨ *Ashuanipi Complex: undifferentiated gneisses*

---

3) the allochthon is dominated by a homogeneous sillimanite–biotite–garnet–magnetite paragneiss unit that extends eastward beyond Churchill Falls, whereas the parautochthon comprises a supracrustal sequence that includes marble, psammitic and pelitic metasediments and mafic metavolcanic rocks.

Other distinctions of a structural and metamorphic nature include:

1) foliations within the parautochthon trend northwest due to a late cross-folding event, whereas fabrics within the Lac Joseph allochthon trend between north to northeast; and

2) the metamorphic assemblages in the pelitic supracrustal rocks within the respective terranes are distinct; the sillimanite–biotite–garnet–magnetite assemblage in restites is unique to the allochthon, in contrast to the biotite–garnet–hornblende± muscovite-bearing restite of the pelitic paragneisses within the parautochthon. Although a progressive increase in metamorphic grade toward the east could account for the different metamorphic assemblages (as was originally proposed by Rivers, 1983b), it seems unlikely that a prograde-reaction isograd would coincide with a boundary separating the lithologically and structurally distinct units. Moreover, the paragneisses in the allochthon commonly contain two distinct leucosomes, whereas in areas where the metasediments within the parautochthon have experienced partial melting, only one leucosome is recognized.

In spite of the discontinuous exposure within the boundary zone, several mylonite zones were observed. Near Lac Emerillon (Figure 2), Attikamagen Formation (lower Knob Lake Group) and granite have been mylonitized to form a northwest-trending straight belt about 100 m wide that is characterized by straight gneissic banding, ribbon quartz, extensive lineation development and pulled-apart pegmatitic dykes (Plate 4). This zone dips moderately to the southwest and is interpreted to have been affected by the late northwest-trending cross folds. After unfolding these mylonite layers about a northwest-trending, subhorizontal fold axis (assuming they are not overturned), scarce kinematic indicators (rotated feldspar and C/shear band relationships) imply that upper-plate rocks to the southeast moved northwestward over the parautochthon. Unmylonitized gabbro of the Shabogamo Intrusive Suite lies structurally above this mylonite zone; assuming that the mylonite zone formed coevally with the emplacement of the Lac Joseph allochthon, the presence of parautochthonous rocks above this shear zone implies that there must be an imbricated series of faults or shear zones which are collectively responsible for the emplacement of the allochthon rather than a single zone.

K-feldspar-megacrystic granite (locally rapakivi textured) occurs along the allochthon–parautochthon boundary. This unit, although highly strained, does not show mylonitic fabrics (Plate 5).

Rocks in the Lac Joseph allochthon close to the mapped boundary of the parautochthon do not show evidence of high strain. However, several outcrops about 11 km east of the boundary within the allochthon exhibit well-developed mylonitic fabrics, including C/S fabrics, shear bands,

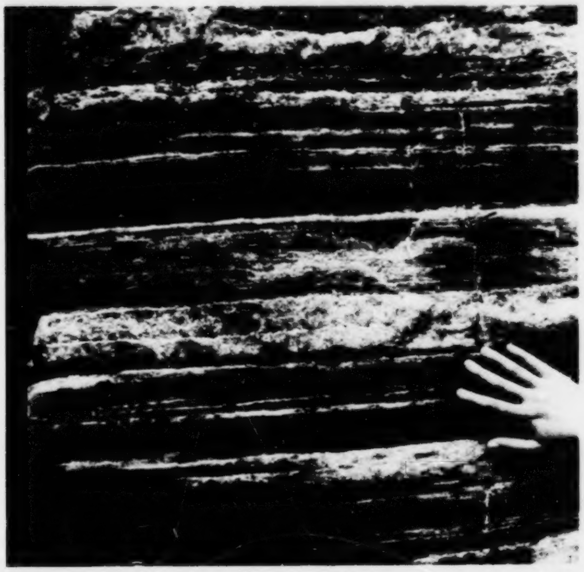


Plate 4. *Mylonitized Knob Lake Group (dark bands) interlayered with granitic sheets along the margin of the Lac Joseph allochthon–parautochthon boundary near Lac Emerillon.*

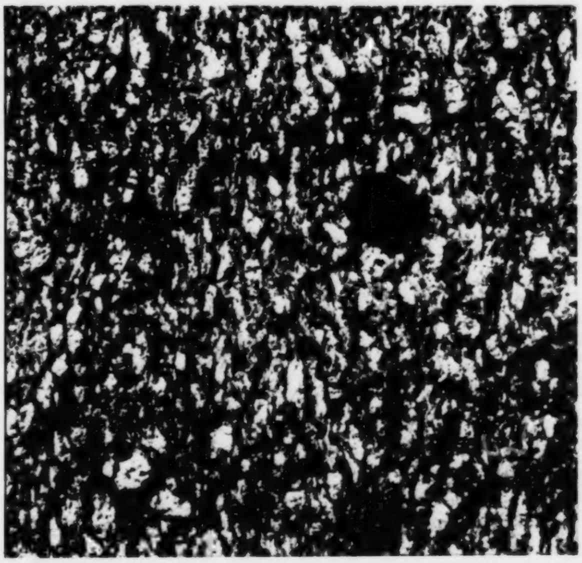


Plate 5. *K-feldspar-megacrystic granite along the Lac Joseph allochthon–parautochthon boundary north of Ross Bay Junction.*

slickensides, and asymmetrically pulled-apart pegmatites. Collectively, these indicate that the southeast block travelled northwest in a reverse motion.

Area B: Panchia Lake Area

Previous work by Nunn and Christopher (1987) and Wardle (1982) has resulted in the identification of the north-south-trending Atikonak Lineament (Figure 2) which separates a predominantly intrusive terrane with minor mixed supracrustal rocks (collectively comprising the parautochthon) in the east, from a paragneiss terrane that forms part of the Lac Joseph allochthon. Previous reconnaissance mapping along the poorly exposed lineament failed to correlate the lineament with high-strain rocks. However, a very low water level within Ossokmanuan Lake during the summer of 1987 has exposed outcrops that reveal locally developed, strongly deformed and mylonitized paragneiss (Plate 6), megacrystic granite and mafic gneiss along the Atikonak Lineament. This high strain zone is vertically dipping with a moderately plunging stretching lineation on the foliation surface. Kinematic indicators within this zone are poorly developed to absent, precluding speculation about tectonic transport direction. The present orientation probably reflects the effects of the latest folding event rather than the mylonite-forming event.

Plate 6. *Inhomogeneously mylonitized sillimanite-bearing paragneiss along the eastern margin of the Lac Joseph allochthon on Ossokmanuan Lake.*

The area immediately west of the high strain zone is mainly underlain by sillimanite-bearing paragneiss, typical of the Lac Joseph allochthon elsewhere, and subordinate amounts of megacrystic granite.

Within the parautochthon east of the high strain zone, granitoid orthogneiss (Plate 7) appears to have undergone at least one stage of deformation and metamorphism (grades up to upper-amphibolite facies). Mafic intrusive rocks range

Plate 7. *Granitoid orthogneiss within the Churchill Falls terrane of the parautochthon east of the Lac Joseph allochthon on Ossokmanuan Lake.*

from undeformed to moderately foliated. The plagioclase-, clinopyroxene-, garnet-, magnetite-bearing gabbro within this area is correlated with the Shabogamo Intrusive Suite on the basis of mineralogy and the coronitic texture.

Correlation of the deformation and metamorphism across the high strain zone is difficult. The granitic rocks may be traced from foliated granites of the Trans-Labrador batholith granitoid rocks in the lower grade areas to the north, into progressively higher grade and more highly deformed orthogneisses toward the south (Wardle, 1982; Rivers and Nunn, 1985). In the north, granitoid rocks have yielded U–Pb zircon dates of ca. 1650 Ma, an age typical of Trans-Labrador batholith rocks (Nunn *et al.*, 1985); in the higher grade areas, U–Pb analyses of zircons have yielded discordant ages with an upper intercept of 1650 Ma and a lower intercept of 993 Ma (no errors given, Rivers and Nunn, 1985). Some U–Pb ages from sphene are concordant at 998 Ma whereas others are discordant and yield upper and lower intercepts of 1653 and 993 Ma respectively (no errors given, Rivers and Nunn, 1985). The paragneisses within the Lac Joseph allochthon have not been dated within the map area, but are believed to have formed at 1650 Ma on the basis of ages obtained from comparable rocks (Nunn *et al.*, 1985) that do not show signs of subsequent thermal resetting. Collectively these dates suggest that the 1650 Ma paragneiss terrane of the allochthon may have been emplaced next to the 1650 Ma intrusive terrane, which was then reworked during the Grenvillian Orogeny at ca. 1000 Ma. This scenario requires that the allochthon and parautochthon experienced different metamorphic conditions during the Grenvillian Orogeny. Their present juxtaposition, together with the apparent metamorphic discontinuity, reinforces the interpretation that there is a significant tectonic break between the two terranes.

Area C: Northern Boundary of the Lac Joseph Allochthon: Map Sheets 23H/5, 6, 11(S), 12(S) and 23G/8 and 9

Map sheets 23H/11 and 12 and 23G/8 and 9 have been previously mapped by Rivers (1985b,c,d), but with a minimal amount of helicopter service available to cover the outlying areas. With increased helicopter support this past summer, reconnaissance mapping within important, but inaccessible, parts of this region has supplemented the original mapping. Map sheets 23H/5 and 6 had not been previously mapped by the Newfoundland Department of Mines.

This area may be divided into three distinct domains on the basis of rock types. The southern domain is thought to belong to the Lac Joseph allochthon whereas the two northern domains show lithological affinities with the parautochthon.

The southern domain, located in the map area covered by sheets 23H/5 and 6, and the areas immediately to the north and west, primarily comprises gabbronorite and gabbro, but includes subordinate amounts of sillimanite paragneiss. The gabbronorite suite ranges from fine- to medium-grained and is composed of plagioclase–clinopyroxene–orthopyroxene–magnetite±garnet±olivine. Plagioclase in the gabbro is typically recrystallized to a fine grained, granular matrix that hosts coarser grained mafic minerals. Sillimanite-bearing paragneiss is only locally exposed within the topographically lower, typically drift-covered areas. Rocks in this unit are similar to sillimanite-bearing paragneiss elsewhere in the Lac Joseph allochthon (i.e., see Area A above). The gneissic layering has been refolded into north- to northwest-trending isoclinal folds that have fold axes parallel to aligned sillimanite plunging moderately toward the southeast.

The central and northern domains of area C are thought to constitute the parautochthon. The central domain is underlain by medium grained gabbro and gabbronorite and muscovite–biotite granite, rock types that are typical of the parautochthonous terrane elsewhere (Connelly and Scowen, 1987). Most of the gabbroic rocks contain plagioclase–clinopyroxene–garnet–magnetite±orthopyroxene, commonly exhibit corona textures and have partially retained a primary igneous texture. Based on these criteria, this unit is correlated with the Shabogamo Intrusive Suite. A second gabbro unit, informally referred to as the Mount Fyne gabbro (G. Nunn, personal communication), is characterized by an unrecrystallized ophitic and/or cumulate texture and locally developed primary igneous layering. The age of this unit is unknown. The granite is equigranular, medium grained and is weakly to moderately foliated.

The northern domain, mapped in detail by Rivers (1985b,c), is distinguished from the central domain by the presence of abundant supracrustal rocks, ranging from pelitic schist to mafic metavolcanic rocks, and by a lack of granite. Rocks of the Shabogamo Intrusive Suite are common to both domains, and are present as fine- to medium-grained gabbro. The few metavolcanic outcrops within the northern domain appear to contain stable, syntectonic chlorite and actinolite. This upper-greenschist- to lower-amphibolite-facies subassemblage contrasts sharply with the upper-amphibolite-facies assemblage from within the paragneisses of the allochthon to the south. Unfortunately, the intrusive character of the central domain precludes comparisons of metamorphic facies.

The intraparautochthon boundary between the central and northern domains is not well exposed, however, a tectonic break is postulated for this zone based on the discontinuity of rock types across this line and the local presence of clearly mylonitized metasediments at the contact. C/S fabrics within this zone are consistent with the allochthon–parautochthon boundary fault zone, and indicate a reverse sense of south-side-up movement.

The boundary zone between the allochthon and parautochthon is best exposed within the eastern part of map area C at Ossokmanuan Lake, where sillimanite-bearing paragneiss, gabbro of the Shabogamo Intrusive Suite and megacrystic granite are locally mylonitized and tectonically intercalated. The mylonitic fabrics vary in appearance and intensity according to rock type. Mylonitic layers within the paragneisses along the northern margin of the allochthon (Plate 8) are characterized by ribbon quartz, prominent stretching lineations on the foliation surfaces, pulled-apart leucosomes and rounded feldspar porphyroclasts. The mylonitic layers tend to be homogeneously developed over tens of metres. The mylonitized gabbro typically exhibits large strain gradients over several metres (Plates 9 and 10); in the zones of highest strain, plagioclase is extensively recrystallized and wraps around clinopyroxene porphyroclasts. Hinge lines of folds, developed within mylonitic layers, approach parallelism with the flow plane with increasing strain. Mylonitized granite, present as discrete shear zones within weakly deformed gabbro (Plate 11), contains ribbon quartz and plagioclase that wrap around K-feldspar megacrysts to form planar and linear fabrics.

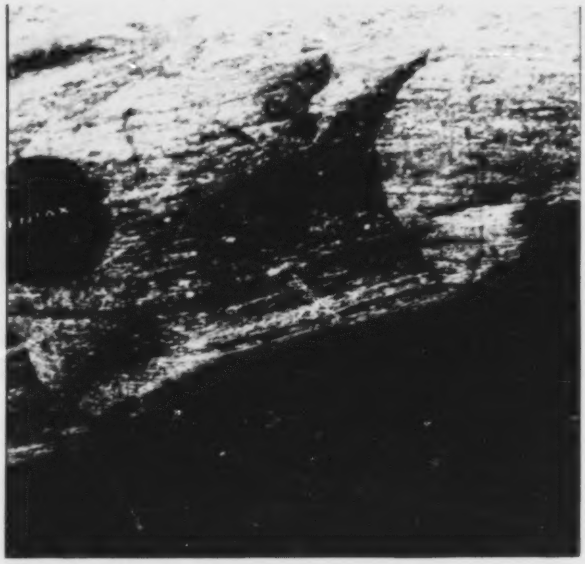


Plate 8. *Mylonitized sillimanite-bearing paragneiss along the northern margin of the Lac Joseph allochthon; the mylonitic fabric is cut by a gabbro dyke (bottom part of photoraph) of uncertain affinity.*

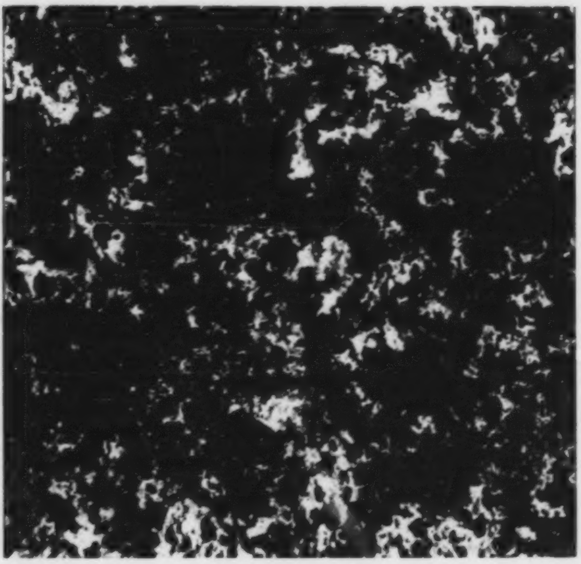


Plate 9. *Coarse grained gabbro of the Shabogamo Intrusive Suite along the northern shore of Ossokmanuan Lake at the boundary between the Lac Joseph allochthon and the parautochthon.*

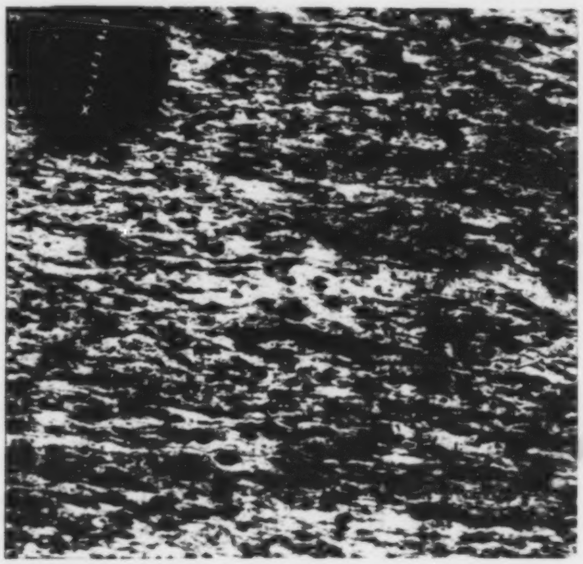


Plate 10. *A mylonitized equivalent of the gabbro shown in Plate 9, but photographed only 2.5 m away.*

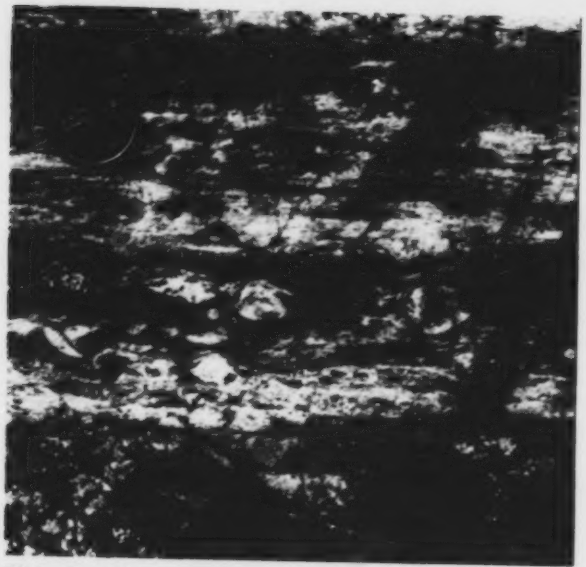


Plate 11. *Mylonitized megacrystic granite sheets within the gabbro along the Lac Joseph allochthon–parautochthon boundary on Ossokmanuan Lake.*

Mylonitic fabrics at several outcrops along the northern margin of the allochthon are cut by gabbronorite dykes (Plate 8). In these locations along the allochthon–parautochthon boundary, there are at least four possible affinities and ages of these dykes: 1) they may emanate from the gabbronorite bodies from within the allochthon; 2) they may be related to the Shabogamo Intrusive Suite from within the parautochthon; 3) they may represent late posttectonic diabase dykes, as yet unrecognized in this area; or 4) they may be related to the Mount Fyne gabbro, also from within the parautochthon. If either 1) or 2) is correct, the mylonites must have formed prior to the Grenvillian Orogeny. The uncertain age of the Mount Fyne gabbro or any potential late dykes precludes speculation about timing of the mylonitization, should scenarios 3) or 4) be correct.

Area D: Ashuanipi Lake

In spite of the extremely poor exposure within the Ashaunipi Lake area, this region was superficially examined in an attempt to correlate Rivers' (1985a) mapping in the 23B/16 and 23B/9 sheets with the mapping of Connelly and Scowen (1987) in the adjoining map sheets 23B/8 and 23B/1 to the south.

The northern part of the Ashuanipi Lake area is underlain by sillimanite-bearing paragneiss and a K-feldspar-megacrystic, rapakivi-textured granite, both typical of the Lac Joseph allochthon. Several outcrops of paragneiss examined on islands in the central part of the lake are reported to contain kyanite by Rivers (1983b). The occurrence of kyanite is atypical within the Lac Joseph allochthon where sillimanite is characteristic. The occurrence of kyanite along the western margin of the allochthon may indicate an increase in pressure from the centre of the allochthon toward the parauthochthon. This model is compatible with pressures in excess of 10 kbar within the parautochthon, which has been documented in preliminary P–T work by the author.

Toward the southern part of Ashuanipi Lake, gabbroic units are more voluminous and, in places, sillimanite-bearing paragneiss is absent. These gabbroic rocks vary in composition from gabbro to gabbronorite, and may be either unrecrystallized and massive, or recrystallized with garnet corona textures and with or without a tectonic fabric.

Several outcrops of layered metasedimentary rocks, thought to be part of the Knob Lake Group, occur within the southwestern part of Ashuanipi Lake. In contrast to the paragneisses to the north, these rocks have not experienced partial melting and appear to contain syntectonic chlorite and amphibole. The map of Rivers (1985a) shows these metasediments intruded by gabbro of the Shabogamo Intrusive Suite.

The association of upper-greenschist- to lower-amphibolite-grade metasedimentary rocks and Shabogamo Intrusive Suite gabbro suggests the southwestern part of Ashuanipi Lake is of parautochthonous affinity. Although the boundary is not exposed, the proximity of this lower-grade terrane with the terrane dominated by upper-amphibolite-facies paragneiss to the northeast suggests that a significant break may exist underneath the lake. This break would represent an extension of the boundary between the parautochthon and allochthon to the south suggested by Connelly and Scowen (1987). Mapping the location of the break is hampered by poor exposure and the uncertain affinity of the gabbro within the southern part of the lake.

Area E: Lac Joseph

With the limited availability of detailed mapping in western Labrador, the definition of the Lac Joseph allochthon margin has relied heavily on aeromagnetic surveys to supplement the reconnaissance mapping. The allochthon is characterized by high and locally variable magnetic intensities relative to the more subdued pattern characteristic of the surrounding parautochthon. In the Lac Joseph area, situated near the centre of the Lac Joseph allochthon, the characteristic high magnetic signature is flanked by a magnetic low to the northwest. Mapping within this well-exposed area was intended to investigate the occurrence of this atypical magnetic pattern and provide additional information about the paragneisses within the Lac Joseph allochthon.

The central part of Lac Joseph is underlain by an intrusive terrane consisting of medium grained, weakly to moderately deformed metagabbro to metagabbronorite comprising plagioclase–clinopyroxene–orthopyroxene–garnet–magnetite and very rarely olivine. The garnet occurs as rims on clinopyroxene and less commonly on orthopyroxene. Elsewhere orthopyroxene has clinopyroxene rims. The mineralogy and textures found within this unit implies that it is correlative with the Shabogamo Intrusive Suite gabbros of the parautochthon.

This central intrusive terrane is flanked to the east and west by sillimanite-bearing paragneisses and interlayered mafic gneisses. The sillimanite-bearing paragneisses exhibits two extensively developed, distinct leucosomes. An early grey leucosome is fine grained, biotite rich and typically foliated and lineated, whereas the later pink leucosome is coarser grained, contains less biotite and is commonly unfoliated. The restite comprises sillimanite–biotite–garnet–magnetite except near granitoid pegmatite veins where sillimanite is statically overgrown by muscovite.

A 500-m-wide continuous band of mafic gneisses underlies the area between the sillimanite paragneisses and western margin of the central intrusive domain. This zone contains relict orthopyroxene but is pervasively retrogressed to amphibolite-facies assemblages. Away from the central intrusive domain, small amounts of mafic gneiss are interlayered with sillimanite-bearing paragneiss, but these mafic gneisses do not appear to have been retrogressed.

The gabbro of the central intrusive terrane is never observed to intrude the gneisses in the adjacent terrane. Several outcrops along the terrane contact exhibit high strain features, such as ribbon quartz, feldspar porphyroclasts and anomalously straight banding (Plate 12). The presence in this area of gabbro of the Shabogamo Intrusive Suite, a unit that to date has only been found within the parautochthon, and the presence of the mylonitic high strain zone along the contact, suggests that the central part of Lac Joseph represents a small tectonic window (fenster) through the allochthon that exposes the structurally underlying parautochthonous terrane. Fluids necessary for the retrogression of the mafic gneisses that has occurred along the domain boundaries may have been derived from the parautochthon during the emplacement of the allochthon.

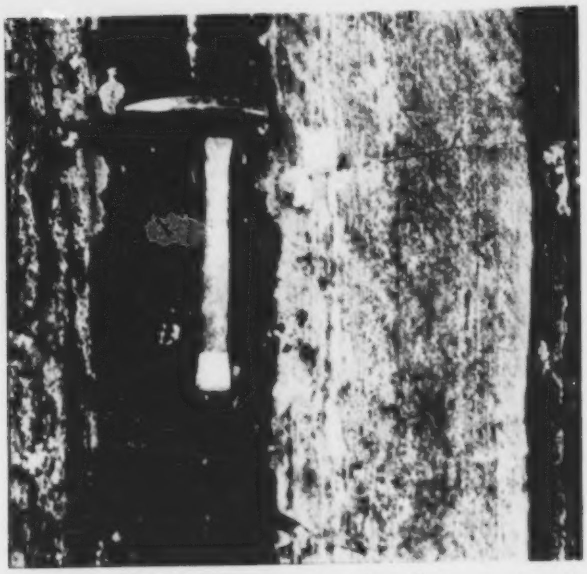


Plate 12. *Mylonitized mafic gneiss along the western margin of the window of the Shabogamo Intrusive Suite exposed at Lac Joseph in the centre of the Lac Joseph allochthon.*

Despite the identification of rocks of parautochthonous affinity in the Lac Joseph area, the surface distribution of rock types belonging to the respective terranes does not correspond to the aeromagnetic patterns. If the contact between paragneisses and the Shabogamo Intrusive Suite is shallow, as is likely, the magnetic patterns may reflect the subsurface distribution of the units.

DISCUSSION

The mylonites along the boundary between the Lac Joseph allochthon and the parautochthon tend to be narrow bands with variable orientations attributed to post-mylonitization folding. In order to determine a sense of relative motion from the relatively few unambiguous kinematic indicators in several outcrops, it is necessary to rotate the mylonitic layering about the local average fold axis–L lineation through the smallest angle such that the strike of the layering is perpendicular to the approximately horizontal fold axis after rotation; this method assumes that the layering has not been overturned. Results of this exercise suggest that the Lac Joseph allochthon moved northwestward to northward over the parautochthon.

The timing of the mylonitization and emplacement of the Lac Joseph allochthon is uncertain. A summary of the relevant information reveals that: 1) the paragneisses within the allochthon developed during the 1650 Ma Labradorian Orogeny; 2) the U–Pb systematics in the Lac Joseph allochthon were not reset during the Grenvillian Orogeny, indicating that the allochthon did not experience a major thermal event at that time; 3) although complicated by Hudsonian effects to the north and local Labradorian effects southeast of Churchill Falls, the main metamorphism within the parautochthon is thought to have occurred during the Grenvillian Orogeny on the basis of regional mapping (Wardle, 1982; Rivers, 1985a,b,c,d; Nunn and Christopher, 1987), partially or completely reset U–Pb systematics in zircon and sphene (Nunn *et al.* 1985; Rivers and Nunn, 1985), and growth of metamorphic sphene at this time (Nunn *et al.*, 1985; Rivers and Nunn, 1985); 4) the 1375 Ma Shabogamo Intrusive Suite is structurally deformed; and 5) there is a lack of any known 1650 Ma tectonothermal effects in the parautochthon west of Ossokmanuan Lake in the Gagnon terrane (Rivers *et al.*, *in press*). Given the present juxtaposition of the Lac Joseph allochthon and the parautochthon and the evidence that suggests that they apparently formed predominantly during two separate events, together with the restriction of the 1375 Ma Shabogamo Intrusive Suite to the parautochthon, it seems most likely that the allochthon was emplaced during the Grenvillian Orogeny.

The gabbro dykes crosscutting the mylonitic fabric within sillimanite-bearing paragneiss in shear zones along Ossokmanuan Lake are enigmatic. Although no gabbroic intrusions younger than 1400 Ma have been documented in maps of either terrane, T. Rivers (personal communication) has seen small posttectonic diabase dykes near Wabush. Thus, these dykes may correlate with them. Alternatively, these dykes may emanate from the presently undated Mount Fyne gabbro exposed east of the shear zone. However, until it can be shown that the dykes are related to post-Grenville magmatism, the possibility that this shear zone, or part of it, may predate the Grenvillian Orogeny must be borne in mind.

Within area C, the intrusive central domain to the north and northwest of the allochthon is abruptly replaced by metasediments of the Knob Lake Group and also gabbro of the Shabogamo Intrusive Suite. The abrupt contact at this location is interpreted to represent an intraparautochthon thrust, which may have formed coevally with the emplacement of the allochthon. This zone may merge with the main allochthon–parautochthon shear zone to the west, such that a more transitional boundary may exist between domains dominated by intrusive and supracrustal rocks west of Labrador City. The extension of this fault zone to the east through Ossokmanuan Lake is uncertain (see Figure 2); it may be overprinted by the Mount Fyne gabbro if this unit postdates the mylonitization as previously discussed.

The metamorphic affects on the Lac Joseph allochthon during its emplacement may be restricted to retrogression along the allochthon margins. For example, the amphibolite-facies retrogression in the mafic gneisses exposed near the parautochthon fenster of gabbro (Shabagamo Intrusive Suite) within the Lac Joseph area, and the local synkinematic retrogression of sillimanite to muscovite along the margins (Connelly and Scowen, 1987) may be attributed to the upward movement of hydrous fluids from the parautochthon into the allochthon during and after its emplacement. ^{40}Ar/^{39}Ar dating on the retrograde amphibole and muscovite will be attempted.

CONCLUSIONS

1. Rock types, metamorphic grade and to a lesser extent the structural styles within the Lac Joseph allochthon, are distinct from those in the adjacent parautochthon.

2. The presence of two distinct leucosome phases within paragneisses within the allochthon contrasts with the single leucosome typical of the areas within the parautochthon that have undergone partial melting. The later leucosome within the allochthon may represent a second pulse of melting during the Labradorian Orogeny or, alternatively, may have formed during the Grenville Orogeny. A sample of younger leucosome suitable for U–Pb dating has been collected.

3. Although generally poorly exposed, mylonite zones have been located at over 20 localities along the parautochthon–allochthon boundary. Field evidence suggests that the Lac Joseph allochthon was emplaced toward the north-northwest over the parautochthon along a series of shear zones rather than a single major shear zone. This fact, combined with the poor exposure, may explain the relative obscurity of mylonites in some exposed areas that are thought to be near or at the boundary.

4. Although the gabbroic units in the allochthon or parautochthon can be generally distinguished, those occurring along the northern margin of the Lac Joseph allochthon and in the Ashuanipi Lake area were not easily categorized in the field. Since the positioning of the allochthon boundary in areas of poor exposure depends largely on contrasting rock types, the location of the boundary in these areas should be considered tentative pending thin section examination and geochemistry.

5. Although the timing of the emplacement of the Lac Joseph allochthon is not dated isotopically, it must have occurred post-1375 Ma, the age obtained from the Shabogamo Intrusive Suite. The partial resetting of several U–Pb zircon and sphene dates from orthogneiss in the parautochthon to ca. 1150 Ma to ca. 1000 Ma and the generation of sphene at ca. 1000 Ma suggests that the allochthon emplacement probably occurred during the Grenvillian Orogeny. This does not preclude that some shear zones within the allochthon or near the margin may have formed originally at 1650 Ma.

6. The gabbro exposed within the Lac Joseph area is correlated with the Shabogamo Intrusive Suite, and is interpreted as a fenster of parautochthon underlying the allochthon.

ACKNOWLEDGMENTS

I am indebted to Kathy Manser for her competent assistance and friendship during the field season. The efforts of the accommodating staff at Ashuanipi Aviation of Labrador City went beyond the regular call of duty and are gratefully acknowledged. Gaetin Viens and Jacques Levesque of Viking Helicopters provided first rate helicopter service and were a pleasure to work with. Ken O'Quinn, Wayne Tuttle and Richard White are thanked for their efficient expediting on our behalf. Midseason visits to the field by G. Nunn and T. Rivers were extremely helpful and much appreciated. This paper benefited greatly from critical reviews by G. Nunn, P. O'Neill and T. Rivers.

REFERENCES

Brooks, C., Wardle, R.J. and Rivers, T.
1981: Geology and geochronology of Helikian magmatism, western Labrador. Canadian Journal of Earth Sciences, Volume 18, pages 1211-1227.

Connelly, J.N. and Scowen, P.
1987: Geology of the Lac Caopacho–Lac Fleur-de-May area, southwestern Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 225-235.

Dallmeyer, R.D.
1982: $^{40}Ar/^{39}Ar$ incremental-release age of biotite from a gabbro of the Shabogamo Intrusive Suite, southwestern Labrador. Canadian Journal of Earth Sciences, Volume 19, pages 1877-1881.

Nunn, G.A.G., Noel, N. and Culshaw, N.G.
1984: Geology of the Atikonak Lake area, Grenville Province, western Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-1, pages 30-41.

Nunn, G.A.G., Thomas, A. and Krogh, T.E.
1985: The Labradorian Orogeny: geochronological database. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 43-54.

Nunn, G.A.G. and Christopher, A.
1987: Geology of the Atikonak River area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File Map 87-07.

Rivers, T.
1983a: The northern margin of the Grenville Province in western Labrador—anatomy of an ancient orogenic front. Precambrian Research, Volume 22, pages 41-73.

1983b: Progressive metamorphism of pelitic and quartzofeldspathic rocks in the Grenville Province of western Labrador—tectonic implications of bathozone 6 assemblages. Canadian Journal of Earth Sciences, Volume 20, pages 1791-1804.

1985a: Geology of the Opacopa Lake area, Labrador—Quebec. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 85-24.

1985b: Geology of the Gabbro Lake area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 85-26.

1985c: Geology of the Evening Lake area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 85-27.

1985d: Geology of the Wightman Lake area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 85-28.

Rivers, T. and Nunn, G.A.G.
1985: A reassessment of the Grenvillian Orogeny in western Labrador. *In* The Deep Proterozoic Crust in the North Atlantic Provinces. *Edited by* A.C. Tobi and J.L.R. Touret. NATO Advanced Study Institute, Series C, Volume 158, pages 163-174.

Rivers, T. and Chown, E.H.
1986: The Grenville Orogen in eastern Quebec and western Labrador—definition, identification and tectonometamorphic relationships of autochthonous, parautochthonous and allochthonous terranes. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A. Baer. Geological Association of Canada, Special Paper 31.

Rivers, T., Martignole, J., Gower, C.F. and Davidson, A.
In press: A new tectonic division of the Grenville Province.

Thomas, A., Nunn, G.A.G. and Wardle, R.J.
1985: A 1650 Ma orogenic belt within the Grenville Province of northeastern Canada. *In* The Deep Proterozoic Crust in the North Atlantic Provinces. *Edited by* A.C. Tobi and J.L.R. Touret. NATO Advanced Study Institute, Series C, Volume 158, pages 151-161.

Wardle, R.J.
1982: Geology of the Churchill Falls region. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-1, pages 131-143.

Wardle, R.J., Rivers, T., Gower, C.F., Nunn, G.A.G. and Thomas, A.
1986: The northeastern Grenville Province: new insights. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A. Baer. Geological Association of Canada, Special Paper 31, pages 13-29.

Zindler, A., Hart, S.B. and Brooks, C.
1981: The Shabogamo Intrusive Suite: Sr and Nd isotopic evidence for contaminated mafic magmas in the Proterozoic. Earth and Planetary Science Letters, Volume 54, pages 217-235.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 49-58

GEOLOGY OF THE GOOSE–PINUS RIVERS AREA (13F/3, 4, 5 and 6), CENTRAL GRENVILLE OROGEN, LABRADOR

R.J. Wardle, B. Kjarsgard, L.V.J. Crisby, C. Anstey, M. Harris and B. Lawlor
Labrador Mapping Section

ABSTRACT

Mapping in 1987 focused on the metasedimentary gneiss terrane, which forms much of the Grenville Orogen in central Labrador, and its contact with other lithotectonic terranes to the east and south. The greater part of the map area is underlain by monotonous metasedimentary gneiss disposed in a major overturned structure referred to as the Pinus Synform. In the northeast, this gneiss, intruded by sheets of megacrystic granite, structurally overlies tonalite, granodiorite, quartz diorite and related gneiss of the Susan River quartz diorite and Groswater Bay terrane. In the south, it is infolded with and overthrust by granitic gneiss and amphibolite interpreted to form the northwestern margin of the Mealy Mountains terrane.

Early deformation of Labradorian (ca. 1650 Ma) and/or Grenvillian (ca. 1000 Ma) age was associated with formation of subhorizontal gneissic and migmatitic fabrics under amphibolite- to granulite-facies conditions. Subsequent deformation, probably of Grenvillian age, consisted of isoclinal folding and formation of south-dipping, ductile shear zones. Metamorphic assemblages and associated migmatization suggest similarly high-grade metamorphic conditions. Late Grenvillian deformation produced open folds and basin and dome interferance patterns.

Grenvillian deformation was followed by deposition of the upper Precambrian to lower Paleozoic Double Mer Formation in a graben interpreted to underlie the Churchill River valley. Quartzite clasts in conglomerates of the formation were probably derived from a nearby, but now eroded, middle Proterozoic sequence similar to those of the Seal Lake and Wakeham Bay groups.

It is concluded that all major lithotectonic terranes in the Goose Bay region were linked by common plutonic sequences prior to the Grenvillian Orogeny, though the absolute ages of these terranes and their linkages have yet to be determined.

INTRODUCTION

The area mapped in the 1987 season lies in the interior Grenville Province of central Labrador (Figure 1) where it adjoins ground covered to the east by previous work under this project (Wardle and Ash, 1986; Wardle and Crisby, 1986). The central and southwestern part of the area form a poorly exposed undulatory plateau largely covered by muskeg and glacial drift. The northern and eastern parts are deeply dissected by the Goose, Pinus and Churchill rivers and consequently form rugged and more completely exposed ground. Mapping was carried out by helicopter-emplaced ground traverses in well-exposed areas, and by helicopter traverses in more poorly exposed regions.

The area was first mapped in 1953 (Podolsky, 1955), at a time when it formed part of a mineral concession held by the Newfoundland and Labrador Corporation (Gillet, 1954). Podolsky (1955) recognized that areas north of the Churchill River (Figure 2) were dominated by quartzofeldspathic gneiss, including sillimanite gneiss, whereas the area south of the river consisted of a syenodiorite complex. The presence of a major synform in quartzofeldspathic gneiss north of the river was also noted. Stephenson (1967) included the area in his mapping of the Goose Bay region for the Geological Survey of Canada and confirmed the presence of the synform. He also indicated a belt of gabbroic and monzonitic rocks south of the Churchill River, and conglomerate of the upper Precambrian to lower Paleozoic Double Mer Formation along its banks. Surficial deposits of the area were described by Fulton and Hodgson (1969) in their regional geomorphological study of NTS sheet 13F.

Work on the present project began as part of a three year program designed to complete mapping at 1:100,000 scale of the Goose Bay sheet. Results have been reported in Wardle and Ash (1986) and Wardle and Crisby (1986, 1987).

REGIONAL SETTING

The Goose Bay area lies within the interior Grenville Orogen (Figure 1) and forms part of a belt of high-grade gneiss and plutonic rock. These rocks have given metamorphic and intrusive ages of 1700-1650 Ma that record the effects of the Labradorian Orogeny (Nunn *et al.*, 1985). The rocks were reworked and given their present structural disposition in the Grenvillian Orogeny ca. 1000 Ma.

The Grenville Orogen of eastern Labrador has been divided into several major lithotectonic terranes (Gower and

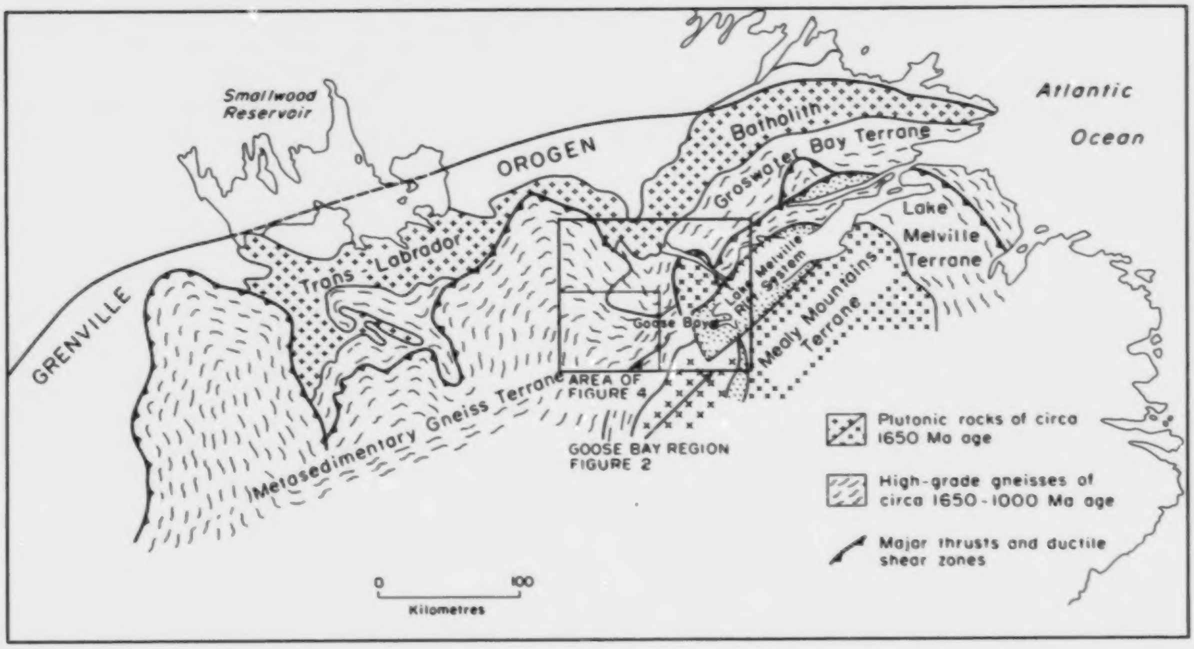

Smallwood Reservoir
Atlantic Ocean
GRENVILLE
OROGEN
Trans Labrador
Batholith
Groswater Bay Terrane
Lake Melville Terrane
Lake Melville Rift System
Mealy Mountains Terrane
Goose Bay
AREA OF FIGURE 4
GOOSE BAY REGION FIGURE 2
Metasedimentary Gneiss Terrane
Plutonic rocks of circa 1650 Ma age
High-grade gneisses of circa 1650-1000 Ma age
Major thrusts and ductile shear zones
0
100
Kilometres

Figure 1. *Location of the map area with respect to tectonic elements of the northeastern Grenville Orogen.*

Owen, 1984; Wardle *et al.*, 1986a) that converge in the Goose Bay region (Figures 1, 2 and 3), making it a focal point for establishing tectonic interrelationships in the interior Grenville Orogen. Granitoid rocks of the Trans-Labrador batholith, dated ca. 1650 Ma, project into the north of the region (Figures 2 and 3). They are adjoined to the east by the extensive Susan River quartz diorite and derived gneiss (Ryan *et al.*, 1982) that pass eastward into similar intrusive rock and granitoid gneiss of the Groswater Bay and Lake Melville terranes (Gower and Owen, 1984). The Lake Melville terrane is overthrust to the south by granodiorite–tonalite gneiss, metagabbro and anorthosite of the Cape Caribou River allochthon (Ryan *et al.*, 1982). This allochthon was proposed by Wardle *et al.* (1986b) to form an extension of the regionally extensive Mealy Mountains terrane, which underlies the southeastern part of the region (Figures 2 and 3). The Mealy Mountain terrane comprises weakly deformed monzonite, metagabbroid rock and anorthosite (Wardle and Crisby, 1987) that is dated to the east of the region at 1640 Ma (Emslie *et al.*, 1983; U–Pb zircon). The Mealy Mountain terrane passes northwestward into a suite of granite and amphibolite gneiss known as the Lower Brook suite, which has been proposed to represent its metamorphosed northern margin (Wardle and Crisby, 1987). The western part of the region is underlain by an extensive suite of metasedimentary gneiss, referred to here as the metasedimentary gneiss terrane. This terrane extends more than 300 km to the west (Figure 1), and is thrust over the Trans-Labrador batholith. The area mapped in 1987 includes the eastern and southern boundaries of the metasedimentary terrane with the Susan River quartz diorite and Mealy Mountains terrane respectively.

Post-Grenvillian development in the region is represented by the upper Precambrian–lower Paleozoic Lake Melville Rift System (Figure 3; Gower, *et al.*, 1986) and associated Double Mer Formation.

GEOLOGICAL DESCRIPTION

Metasedimentary Gneiss (Unit 1)

These rocks, which occupy most of the map area (Figure 4), are divided into three subunits on the basis of field appearance. Subunit 1a comprises a generally grey, banded and migmatitic quartz–feldspar–biotite gneiss and also contains ilmenite and variable amounts of garnet. Sillimanite is locally present as isolated needles or acicular sprays, and indicates a psammitic to semipelitic origin for the bulk of subunit 1a. However, some outcrop areas are formed by relatively massive quartz–feldspar–biotite gneiss that could conceivably be derived from granite, or felsic volcanic rock. Rocks of presumed granitoid origin are present as small outcrop areas of grey, plagioclase-porphyritic granodiorite augen gneiss, prevalent near the contact with Lower Brook suite gneiss. The bulk of subunit 1a is disposed as a discontinuous band around the rim of the Pinus Synform (Figure 4) where it appears to represent a vestige of megascopic stratification.

Subunit 1b forms the bulk of the metasedimentary gneiss and consists of generally pink, migmatitic to banded gneiss of quartz–feldspar–biotite–sillimanite–garnet–ilmenite composition. This sillimanite-rich gneiss is locally intercalated with thin bands of grey sillimanite-deficient gneiss similar to subunit 1a. Contacts are generally gradational and

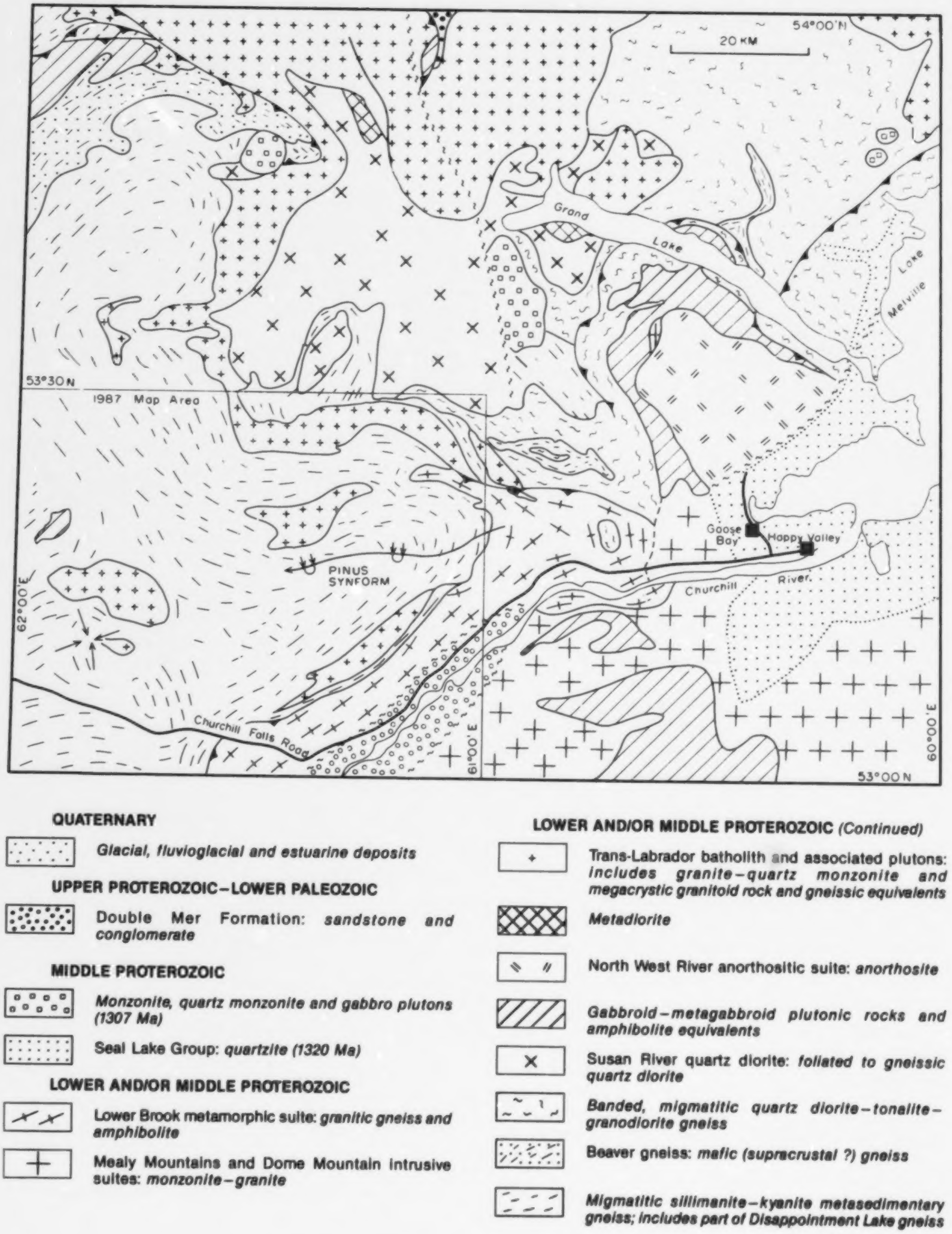

54°00'N
20 KM
Grand Lake
Lake Melville
53°30 N
1987 Map Area
Goose Bay
Happy Valley
Churchill River
PINUS SYNFORM
Churchill Falls Road
62°00'E
61°00'E
60°00'E
53°00 N
QUATERNARY
Glacial, fluvioglacial and estuarine deposits
UPPER PROTEROZOIC–LOWER PALEOZOIC
Double Mer Formation: sandstone and conglomerate
MIDDLE PROTEROZOIC
Monzonite, quartz monzonite and gabbro plutons (1307 Ma)
Seal Lake Group: quartzite (1320 Ma)
LOWER AND/OR MIDDLE PROTEROZOIC
Lower Brook metamorphic suite: granitic gneiss and amphibolite
Mealy Mountains and Dome Mountain intrusive suites: monzonite–granite
LOWER AND/OR MIDDLE PROTEROZOIC (Continued)
Trans-Labrador batholith and associated plutons: includes granite–quartz monzonite and megacrystic granitoid rock and gneissic equivalents
Metadiorite
North West River anorthositic suite: anorthosite
Gabbroid–metagabbroid plutonic rocks and amphibolite equivalents
Susan River quartz diorite: foliated to gneissic quartz diorite
Banded, migmatitic quartz diorite–tonalite–granodiorite gneiss
Beaver gneiss: mafic (supracrustal ?) gneiss
Migmatitic sillimanite–kyanite metasedimentary gneiss; includes part of Disappointment Lake gneiss

Figure 2. *Regional geology of the Goose Bay area (13F). The 1987 map area forms the southwestern quadrant.*

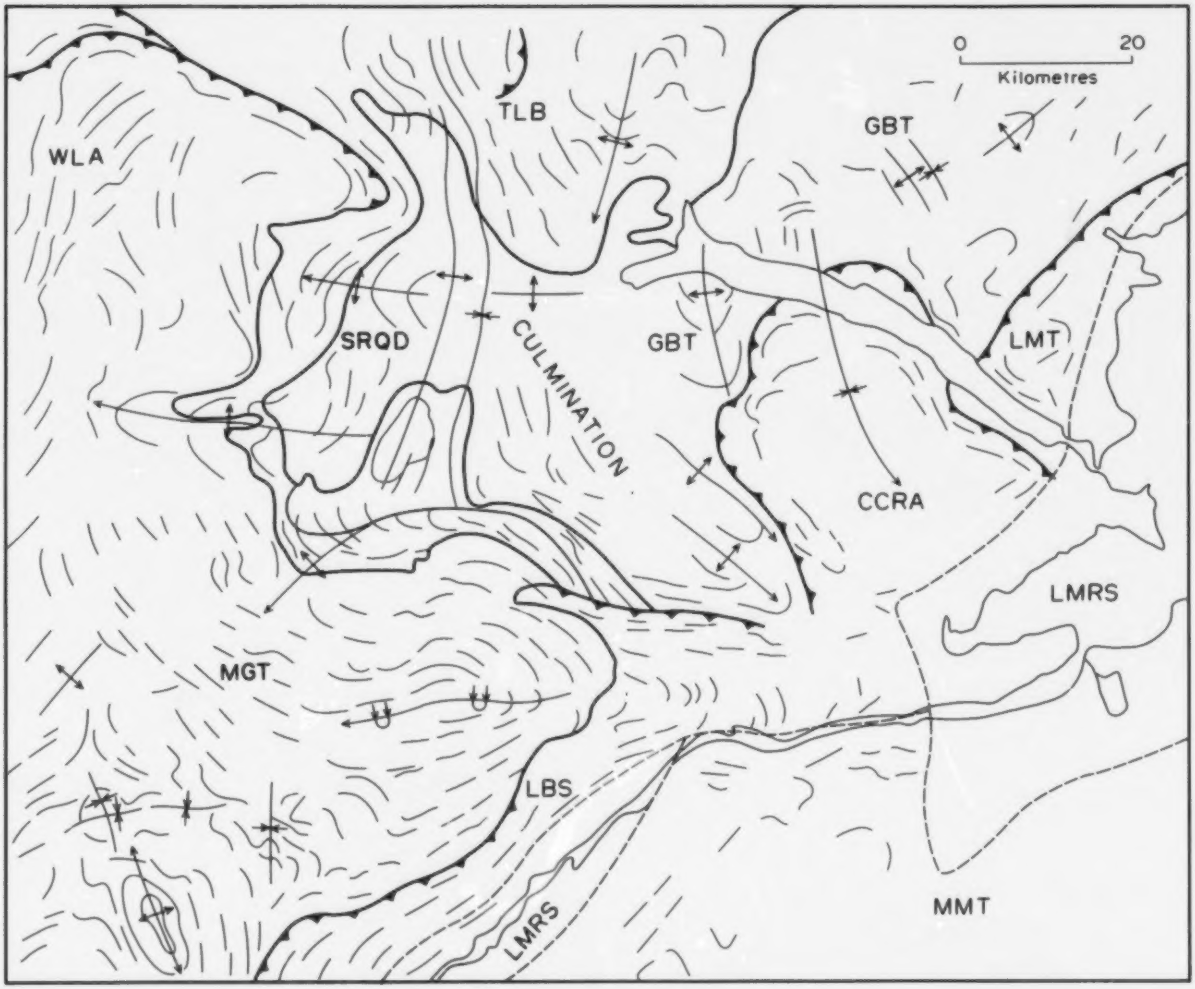


Figure 3. *Major tectonic subdivisions of the Goose Bay area (13F) combined with structural trends. MGT=metasedimentary gneiss terrane; WLA=Wilson Lake allochthon; TLB=Trans-Labrador batholith; SRQD=Susan River quartz diorite; GBT=Groswater Bay terrane; LMT=Lake Melville terrane; CCRA=Cape Caribou River allochthon; MMT=Mealy Mountains terrane; LBS=Lower Brook suite; LMRS=Lake Melville Rift System. Simplified after Ryan* et al., *1982; Thomas* et al., *1983; Erdmer, 1984; Wardle and Ash, 1984; Wardle and Crisby, 1986.*

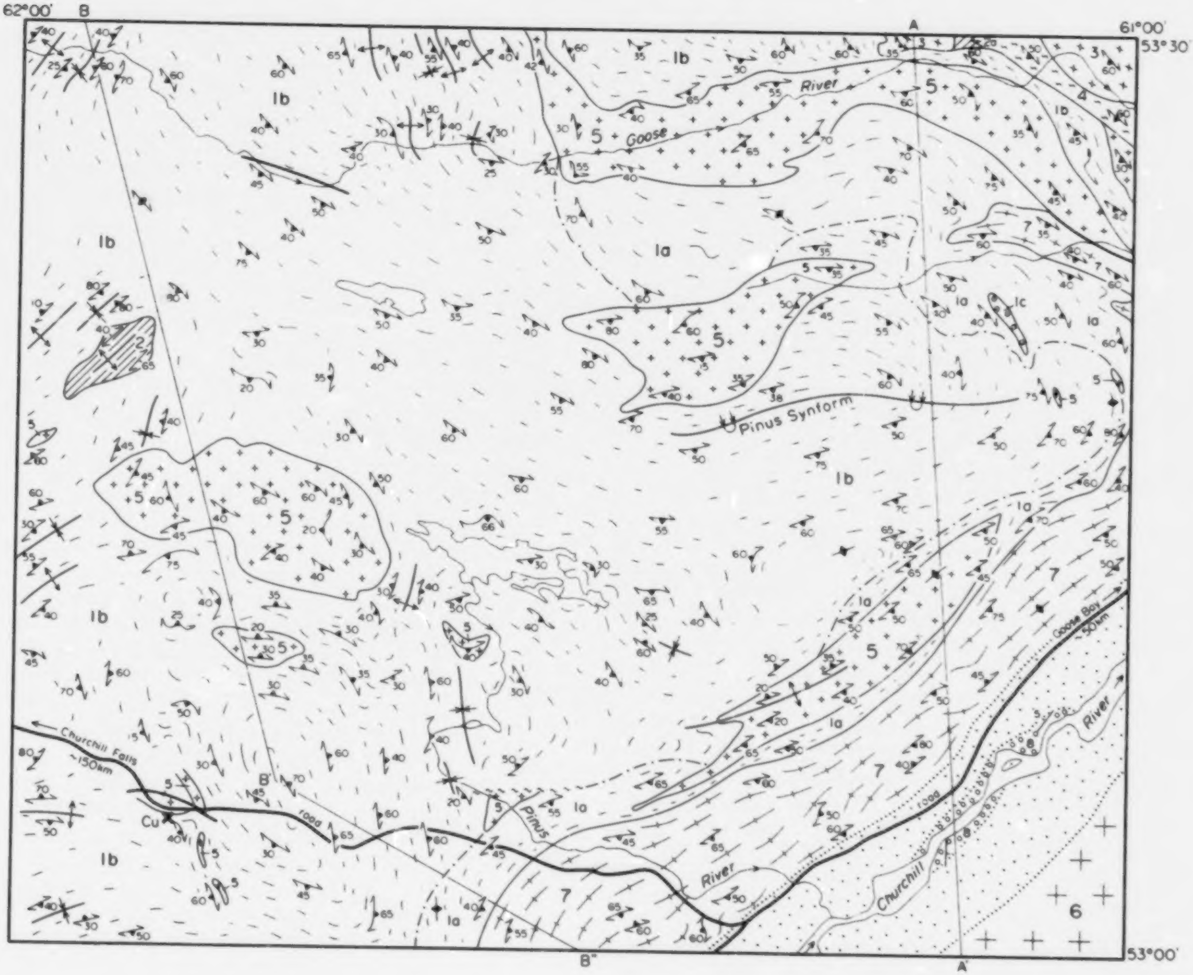
it is likely that the grey gneiss represents psammitic (alumina deficient) layers within the sedimentary protolith.

Subunits 1a and b both contain numerous thin boudinaged bands and isolated pods of hornblende–plagioclase amphibolite likely derived from minor intrusions and mafic volcanic rocks. Banded diopside-bearing calc-silicate rock and angular boulders of white marble (likely of local derivation) have also been found within an area largely underlain by metasedimentary gneiss in the southwestern part of the map area.

Subunit 1c is a small lenticular augen gneiss body of enigmatic origin exposed near the nose of the Pinus Synform. The unit is texturally similar to metasedimentary gneiss, apart from the presence of small (1 to 1.5 cm) K-feldspar augen. Similar rocks are also seen adjacent to contacts with megacrystic granite of Unit 5.

Areas of diatexite, locally identified as separate granite intrusions in previous work (Podolsky, 1955; Stephenson, 1967) are also common over areas of several tens to hundreds of square metres within all variants of Unit 1. They are composed generally of weakly foliated, equigranular to pegmatitic granite containing garnet, biotite, ilmenite, minor clots of sillimanite, and schlieren of metasedimentary gneiss.

The age of the metasedimentary gneiss within the map area has not been established directly. The gneiss is, however, continuous to the northwest with the similar Disappointment


62°00'
B
A
61°00'
53°30'
Goose
River
Pinus Synform
Churchill Falls ~150km
Goose Bay ~50km
Road
Pinus
River
Churchill
River
Cu
B'
B''
A'
53°00'
1a
1b
1c
2
3
4
5
6
7
8

LEGEND

PLEISTOCENE

⁘	*Fluvioglacial sand and clay*

UPPER PROTEROZOIC–LOWER PALEOZOIC

8	Double Mer Formation: *cobble–boulder quartzite conglomerate and red sandstone*

MIDDLE–LOWER PROTEROZOIC

7	Lower Brook metamorphic suite: *pink to grey granitic gneiss, and amphibolite*
6	Mealy Mountains intrusive suite: *weakly foliated monzonite and monzodiorite*
5	*Foliated to gneissic, K-feldspar-megacrystic granitoid rocks*
4	*Grey, migmatitic quartz–feldspar–biotite granodiorite–tonalite gneiss*

MIDDLE–LOWER PROTEROZOIC *(Continued)*

3	Susan River quartz diorite: *grey, quartz–feldspar–biotite–hornblende–garnet quartz diorite*
2	*Amphibolite–mafic granulite; 2a ultramafite and amphibolite gneiss*

Metasedimentary gneisses

1c	*Quartz–feldspar–biotite augen gneiss*
1b	*Pink, quartz–feldspar–biotite–garnet–sillimanite gneiss (sillimanite rich)*
1a	*Grey, quartz–feldspar–biotite–garnet gneiss (local sillimanite)*

SYMBOLS

60 ⟷	*Ductile shear zone*
—·—	*Gradational contact*

Figure 4. *Geology of the Goose–Pinus rivers area (13F/3, 4, 5 and 6).*

Lake gneiss that has yielded dates of ca. 1650 Ma (Thomas *et al.*, 1986).

Amphibolite–Mafic Granulite (Unit 2)

This unit occurs as two mappable bodies (Figure 4) and several widely scattered outcrops interspersed within metasedimentary gneiss of Unit 1. The western body consists of hornblende–plagioclase amphibolite, containing local relict orthopyroxene, intruded by granitoid dykes and pegmatite. Relict orthopyroxene, in association with clinopyroxene, is also found in small outcrops of similar rock type scattered through the north-central part of the map area. The northeastern body (subunit 2a; Figure 4) underlies a small area of deeply weathered schistose ultramafite of uncertain composition, which is associated with isolated outcrops of amphibolite gneiss. The nature of the relationship between the mafic rocks and metasedimentary gneiss is unknown.

Susan River Quartz Diorite and Tonalite (Unit 3)

This unit is present in the northeast of the map area and is contiguous to the north with the regionally extensive Susan River quartz diorite (which also includes diorite, granodiorite and granite) of Ryan *et al.* (1982) (Figure 2). The western part of this unit, north of the Goose River, comprises dark grey, and massive, plagioclase–quartz–biotite–hornblende–garnet intrusive rock of quartz diorite–diorite composition. Biotite defines a strong foliation but the rocks are not generally gneissic. The eastern part of the unit is more heterogeneous in composition, varying from quartz diorite to tonalite and granodiorite (generally containing very little garnet), but is likewise characterized by foliated or lineated, as opposed to gneissic, texture. Ryan *et al.* (1982) noted an intrusive relationship between Susan River quartz diorite and metasedimentary gneiss; however, the absolute age of the plutonic suite has yet to be established.

Granitoid Gneiss (Unit 4)

Unit 4 is spatially associated with Unit 3 and forms a narrow band separating its eastern and western components. It is composed of well-banded quartz–feldspar–biotite gneiss containing minor amounts of hornblende and garnet, and ranges in composition from quartz diorite to granodiorite. The gneiss is identical to more extensive rocks found to the east within the Groswater Bay terrane (Figures 2 and 3), and also resembles gneissic parts of the Susan River quartz diorite (*sensu lato*; Ryan *et al.*, 1982), from which it may in part be derived.

Megacrystic Granitoid Rock (Unit 5)

Megacrystic granitoid rock occurs as several podiform or sheet-like plutons within the metasedimentary gneiss and as scattered plutons too small to be shown in Figure 4. Individual plutons differ substantially in degree of deformation but show broadly similar compositions and are grouped for purposes of description. The northernmost pluton, exposed around the Goose River, forms part of the Trans-Labrador batholith. The unit as a whole is dominated by grey-weathering granitoid rocks containing K-feldspar megacrysts set in a granoblastic to foliated matrix of quartz, plagioclase feldspar, biotite, oxides (predominantly ilmenite) and minor garnet. The composition is principally granitic but varies to granodiorite in megacryst-poor outcrops. Lesser amounts of medium grained, equigranular granite are present, and the Goose River pluton includes a marginal phase consisting of quartz-rich megacrystic granite (1 to 2-cm megacrysts).

The structural state of the unit varies from weakly foliated, in which megacrysts are randomly orientated, to strongly foliated, in which gneissic, migmatitic and mylonitic textures predominate. Foliation is defined by quartz and biotite. In strongly deformed rocks, the megacrysts have recrystallized to augen composed of granoblastic K-feldspar aggregates. Development of foliation, in particular mylonitic fabric, is generally more intense in the southwestern part of the area.

Contacts between Unit 5 and the metasedimentary gneiss of Unit 1 are exposed at several localities on the Goose and Pinus rivers. Some contacts are sharp; most, however, are gradational due to development of small K-feldspar augen (imparting a pseudogranitoid appearance) within metasedimentary gneiss and almost complete recrystallization of megacrystic texture within the granitoids. Augen gneiss, derived from megacrystic granitoid, is repeatedly intercalated with metasedimentary gneiss (Unit 1) in bands several metres to tens of metres in width along a section of the Pinus River extending 4 km upstream of the contact with the Lower Brook suite (Figure 4). The strong deformation and mylonitic texture suggest that this feature is tectonic.

Monzonite–Monzodiorite of the Mealy Mountains Intrusive Suite (Unit 6)

This unit is confined to the area southeast of the Churchill River (Figure 4) where it adjoins an extensive mass of similar rocks correlated by Wardle and Crisby (1987) with the Mealy Mountains Intrusive Suite. Within the map area this suite is represented predominantly by grey- to brown-weathering, medium grained monzonorite, biotite monzodiorite and lesser amounts of gabbronorite, altered metagabbroid and pink monzonite. The metagabbroid rocks are locally seen as inclusions in monzodioritic rocks whereas monzonite appears to be a late phase on the basis of dykes seen to intrude monzodiorite. The suite as a whole contrasts with all other rocks in the map area by virtue of its massive to weakly foliated state. The only indication of its age comes from the eastern Mealy Mountains area from where Emslie *et al.* (1983) have obtained a U–Pb zircon age of 1640 Ma.

Granite Gneiss and Amphibolite of the Lower Brook Metamorphic Suite (Unit 7)

This unit forms a 10-km-wide band between the metasedimentary gneiss of Unit 1 and the massive intrusive rocks of Unit 6, and is correlated with the Lower Brook suite of Wardle and Ash (1986). Granitic gneiss and amphibolite are the dominant rock types within the present map area. The granitic gneiss is a grey- to pink-weathering, weakly to strongly layered rock type containing biotite, hornblende, garnet and clinopyroxene in addition to quartz and feldspar. Layering in the gneiss is largely defined by granite–amphibolite variation and *lit-par-lit* migmatite texture. The pink-weathering colour is clearly a secondary effect associated with late fracturing and is most prevalent near the Churchill River valley.

Migmatite fabrics are locally crosscut by foliated granite dykes and posttectonic pegmatite. The igneous parentage of the granitic gneiss is readily demonstrated in local low-strain areas that preserve homogeneous granite–quartz monzonite containing relict equigranular igneous texture and amphibolite xenoliths.

Amphibolite, consisting of plagioclase+hornblende± clinopyroxene and garnet, is interlayered with granitoid gneiss on a scale of centimetres to metres and may locally form up to fifty percent of outcrop. Scarce enclaves of a coarse grained, leucocratic metagabbroid rock, similar to rock types seen within the gabbroid–anorthosite sequence of the Cape Caribou River allochthon, are also found within the Lower Brook suite.

The contact between the Lower Brook suite and the metasedimentary gneiss is a ductile shear zone, except within the nose of the Pinus Synform. Generally, gneissic layering within the Lower Brook suite has a straight appearance parallel to the contact, and within the shear zone gives way to pink and black, banded, mylonite and ultramylonite gneiss. The shear zone obscures primary relationships between the Lower Brook suite and other map units. However, to the east (Wardle and Ash, 1986) equivalent rocks pass gradationally into foliated plutonic rocks intrusive into tonalite–granodiorite gneiss at the base of the Cape Caribou River allochthon.

Conglomerate and Sandstone of the Double Mer Formation (Unit 8)

Stevenson (1967) described two outcrops of conglomerate and sandstone on the banks of the Churchill River that he correlated with the Double Mer Formation of the Lake Melville area. Despite an extensive search, these two outcrops remain the only exposure of this unit in the map area. Both comprise cobble to boulder conglomerate consisting almost exclusively of quartzite clasts set in a matrix of coarse pink arkose, which is locally cemented by carbonate. The clasts are highly rounded, white to pale green, and very fine grained. They are clearly of sedimentary origin but also show a pervasive recrystallization and weakly developed cleavage that indicate metamorphism of the source lithology. The conglomerate and arkose are crossbedded in tabular sets for which a northwesterly paleocurrent flow is indicated by three measurements. The environment of deposition can only be broadly interpreted as either littoral or fluviatile.

The conglomerate is undeformed and must therefore lie unconformably upon the surrounding rocks. Conglomerate exposures are topographically lower than those of adjacent gneiss and granitoid units, and indicate preservation in an old river channel or a graben. The lack of local detritus in the conglomerate suggests isolation from local sources at time of deposition and is more compatible with the latter interpretation. Klassen and Thompson (personal communication, 1987) have noted abundant rounded quartzite boulders, identical to those described above and inferred to be of local derivation, in tills extending 100 km to the east of the area. This strongly suggests that the conglomerate is the fault-preserved remnant of a preglacially extensive unit. At present, the only quartzite sequences with which the conglomerate and till boulders can be matched are in the middle Proterozoic Seal Lake and Wakeham groups (Brummer and Mann, 1961; Bourne *et al.*, 1977). However, these are relatively distal (more than 100 km), whereas the homogeneity of clast content suggests a proximal source. Presumably, therefore, the conglomerate clasts were derived from a now eroded local quartzite source, which shed detritus into Double Mer fluvial systems during post-Grenville uplift. The Double Mer rocks were subsequently preserved in a graben associated with development of the Lake Melville Rift System (Gower *et al.*, 1986).

STRUCTURE AND METAMORPHISM

Early structural development in the area involved the development of gneissic and migmatitic layering under upper-amphibolite-facies conditions in both metasedimentary and granitoid gneisses. Relict orthopyroxene in mafic rocks indicates the local attainment of granulite-facies conditions in the north-central and southwestern parts of the area. It is uncertain whether early fabric development occurred coevally in all units.

Gneissic fabrics in all rock types, but particularly in the metasedimentary gneiss, have been refolded into tight folds in a second deformational (D_2) event. This was associated with the development of a weak biotite S_2 fabric and a west- to southwest-plunging intersection lineation. A second generation of partial melt is locally seen forming thin veins along the axial planes or limbs of D_2 folds. In D_2 high strain zones, common throughout the metasedimentary gneiss, the folds become isoclinal, develop a strong biotite–sillimanite fabric, and eventually suffer complete transposition into a composite S_1-S_2 fabric. Also, as part of this process, lineation is converted from an intersection to a mineral aggregate lineation, defined by quartz, feldspar and biotite, and progressively rotated into south to southeasterly plunge directions. D_2 deformation culminated in the formation of ductile shear zones, which are localized within the metasedimentary gneiss, at some of its contacts (see below) and within megacrystic granite. This deformation, which is prevalent in the southwestern part of the area, resulted in development of straightened and mylonitic gneiss. Sillimanite in such rocks is aligned within the S-fabric plane but randomly orientated on the S-surface, and only forms a mineral lineation in the most strongly sheared and mylonitic rocks.

The major D_2 ductile shear zones form the contact between metasedimentary gneiss and Lower Brook suite

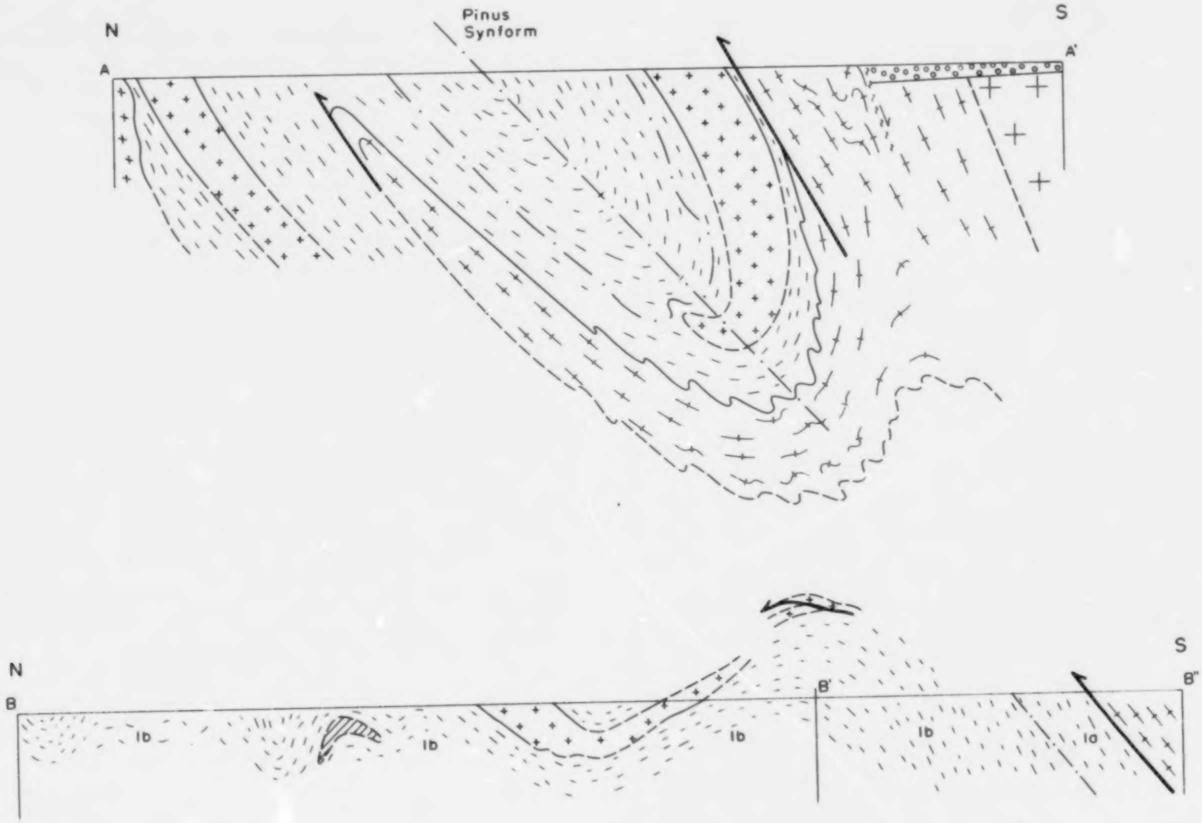


Figure 5. *Structural cross-sections of Goose–Pinus rivers area. Sections are keyed to Figure 4.*

gneiss on the limbs of the Pinus Synform (Figures 4 and 5). Fresh orthopyroxene, in association with clinopyroxene, is locally present in amphibolite–mafic granulite bands within mylonitic Lower Brook gneiss adjacent to both shear zones. Other major shear zones are undoubtedly present within the southwestern part of the area, but, with the exception of a shear zone exposed on the Churchill Falls road, a combination of poor exposure and late folding has prohibited their full delineation. D_2 melt veins and local orthopyroxene in the Lower Brook suite imply that D_2 ductile shearing occurred under upper-amphibolite- to granulite-facies conditions. The random orientation of sillimanite on S-surfaces indicates that the thermal peak of this metamorphism outlasted deformation except within the central parts of some shear zones where the mineral forms a lineation.

The only megascopic fold structure that can be reasonably linked with the D_2 event is the Pinus Synform. This overturned isocline (Figure 5; Section A-A') has a steep southwesterly plunge coincident with the plunge of intersection lineation in minor folds. The presence of the synform is only apparent in its closure region, raising the possibility that other major isoclines may be present in more poorly exposed parts of the map area.

Following shear-zone development, the area was subjected to a period of open folding about irregular but approximately north- and east-trending axes that locally interfered to produce dome and basin patterns (Type 1; Ramsay, 1967). These structures, which affect shear-zone fabrics, F_2 folds and lineation, are most pronounced in the southwestern part of the area, probably because D_2 fabrics in this area had a prior subhorizontal attitude making them sensitive to subsequent folding (Figure 5; Section B-B").

The late folds are correlated with regional structures of similar trend described by Ryan *et al.* (1982) from the area to the northeast. These folds to the northeast are associated with a culmination of Susan River quartz diorite and tonalite–granodiorite gneiss (Figure 3). All structures in the northeastern corner of the present map area have westerly to southerly dips and plunges off this culmination.

In the eastern part of the map area, the latest structures are a series of steep, brittle faults of east to northeast trend that are parallel to well-developed drainage and air photograph lineaments. Faults are locally exposed as narrow zones of brecciation and hematite–silica–epidote–chlorite alteration. The granitoid gneiss of the Lower Brook suite near the

Churchill River is particularly strongly fractured and reddened as a result of this faulting. Fault development is most likely related to development of the upper Precambrian (to lower Paleozoic) Lake Melville Rift System and its Churchill River valley splay, and alteration is probably related to the ingress of oxidizing groundwater from the Double Mer erosion surface.

MINERALIZATION

Mineralization is restricted to a small occurrence of chalcopyrite associated with calc-silicate and sillimanite gneiss in the southwestern part of the area. Podolsky (1955) also reported chalcocite from biotite granite (diatexite of this study) within approximately the same area. Metasedimentary gneiss throughout the map area also contains small scattered concentrations of disseminated ilmenite.

DISCUSSION

The most important aspects of field work in 1987 are the confirmation of the synformal structure first recognized by Podolsky (1955), and the realization that this structure, together with late cross folds, reveals down-plunge sections through a layered part of the Grenvillian crust. The sections show that the metasedimentary gneiss is interlayered with a sheet-form pluton of megacrystic granite and a folded apophysis of Lower Brook suite gneiss and that these lithologies structurally overlie the Susan River quartz diorite and equivalent Groswater Bay terrane gneiss. Whether this has any primary stratigraphic significance is doubtful. Prior to late folding it is likely that most of the gneissic and D_2 fabric elements had subhorizontal or gentle south-dipping attitudes, suggesting an association with nappe-style tectonics. It is thus possible that the observed sequence is entirely the result of structural as opposed to depositional or intrusive control.

U−Pb zircon dating of granulite- and amphibolite-facies gneiss from the remainder of the metasedimentary gneiss terrane of central and western Labrador has yielded largely Labradorian (ca. 1650 Ma) ages (Thomas *et al.*, 1986). Therefore, it is likely that much of the metasedimentary gneiss in the map area, including the retrogressed mafic granulites of Unit 2, was initially metamorphosed to amphibolite-granulite facies in this event. The age of the major shear zones, and by inference the whole D_2 event, is likely to be Grenvillian by comparison with major shear zones along the northern boundary of the metasedimentary gneiss terrane dated at 1046-1088 Ma (Dallmeyer, 1987) (Figure 3). The D_2 event was at least locally associated with partial melting and similar upper-amphibolite- to granulite-facies metamorphism. Consequently, it is unclear to what extent the metamorphic state of the area as a whole is the result of Grenvillian, as opposed to Labradorian, tectonism.

One of the original aims of the Goose Bay project was to elucidate the relationship between the Mealy Mountains terrane and lithotectonic terranes to the north. Evidence collected to date suggests that the Lower Brook suite gneiss represents the metamorphosed northwestern margin of the Mealy Mountains terrane and also that this terrane is connected by intrusive relationships to the Cape Caribou River allochthon. The Mealy Mountains terrane (including the Lower Brook suite) and Cape Caribou River allochthon are bounded on their northwestern sides by a major thrust front of probable Grenvillian age. This front, however, is not a single, continuous structure, but a series of individual thrusts which die out, or root, along strike. Thus gneiss of the Groswater Bay terrane may be traced around the western side of the Cape Caribou River allochthon into similar gneiss forming the basal part of the allochthon, where it is intruded by granitoid plutons contiguous with the Mealy Mountains terrane (Wardle and Crisby, 1987). It is evident, therefore, that Groswater Bay terrane was plutonically linked to the Mealy Mountains terrane prior to Grenvillian deformation.

The contact between the Mealy Mountains terrane (including the Lower Brook suite) and the metasedimentary gneiss terrane is largely tectonic and original relationships have not been deduced. However, to the north of this contact zone, the metasedimentary gneiss terrane is intruded by the Trans-Labrador batholith and Susan River quartz diorite (Ryan *et al.*, 1982). Both of these plutonic units are also in intrusive contact with rocks of the Groswater Bay terrane (although relative age relationships are not clear) and thereby provide indirect evidence of a pre-Grenvillian linkage between the metasedimentary and Mealy Mountains terranes.

The age of the various terranes of the Goose Bay region and their plutonic linkages is still uncertain and is being addressed through a program of radiometric dating. However, it appears reasonably clear that most of the crustal elements of this region were in place by 1000 Ma and that the principal effect of Grenvillian deformation was to rework this crust at high metamorphic grade and telescope it into a series of northwest-verging thrust blocks.

ACKNOWLEDGMENTS

The project was greatly assisted by the expediting services of Department of Mines personnel Wayne Tuttle, Ken O'Quinn and Richard White. Helicopter services were provided by Universal Helicopters of Goose Bay. Andy Kerr is thanked for critically reviewing and markedly improving an earlier draft of this manuscript.

REFERENCES

Bourne, J.H., Stott, G., Borduas, B. and Lalonde, A.
1977: Lac de Morhiban and Natashquan River map areas, Québec. *In* Report of Activities, Part A. Geological Survey of Canada, Paper 77-1A, pages 199-204.

Brummer, J.J. and Mann, E.L.
1961: Geology of the Seal Lake area, Labrador. Geological Society of America Bulletin, Volume 72, pages 1361-1382.

Dallmeyer, R.D.
1987: $^{40}Ar/^{39}Ar$ mineral age record of variably superimposed Proterozoic tectonothermal events in the Grenville Orogen, central Labrador. Canadian Journal of Earth Sciences, Volume 24, pages 314-333.

Emslie, R.F., Loveridge, W.D., Stevens, R.D. and Sullivan, R.W.
1983: Igneous and tectonothermal evolution, Mealy Mountains, Labrador. Joint Annual Meeting. Geological Association of Canada, Mineralogical Association of Canada, Canadian Geophysical Union, Victoria, 1983, Program and Abstracts, Volume 8, page 20.

Erdmer, P.
1984: Precambrian geology of the Double Mer–Lake Melville region, Labrador. Geological Survey of Canada, Paper 84-18, 37 pages.

Fulton, R.G. and Hodgson, D.A.
1969: Surficial geology of the Goose Bay 1:250,000 sheet (13F). Geological Survey of Canada, Open File 29, 16 maps.

Gillet, L.
1954: Horseshoe Rapids. Newfoundland and Labrador Corporation Limited. Unpublished map and legend. Open File [LAB (98)]

Gower, C.F. and Owen, V.
1984: Pre-Grenvillian and Grenvillian lithotectonic events in eastern Labrador–correlations with the Sveconorwegian orogenic belt in Sweden. Canadian Journal of Earth Sciences, Volume 21, pages 678-693.

Gower, C.F., Erdmer, P. and Wardle, R.J.
1986: The Double Mer Formation and the Lake Melville rift system, eastern Labrador. Canadian Journal of Earth Sciences, Volume 23, pages 359-368.

Nunn, G.A.G., Thomas, A. and Krogh, T.E.
1985: The Labradorian Orogeny: geochronological database. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 43-54.

Podolsky, T.
1955: Geology of the Horseshoe Rapids area, Lower Hamilton River, Labrador. Newfoundland Department of Mines and Resources, Mines Branch. Geological Survey report No. 8, 26 pages with map. Available as Newfoundland Department of Mines, Mineral Development Division. Open File [LAB 13F(4)]

Ramsay, J.G.
1967: Folding and fracturing of rocks. McGraw-Hill Book Company, 568 pages.

Ryan, B., Neale, T. and McGuire, J.
1982: Descriptive notes to accompany geological maps of the Grand Lake area, Labrador, 13F/10, 11, 14, 15. Newfoundland Department of Mines and Energy, Mineral Development Division, Maps 8264-67 inclusive, 14 pages.

Stevenson, I.M.
1967: Goose Bay map area, Labrador. Geological Survey of Canada, Paper 67-33, 12 pages.

Thomas, A., Jackson, V. and Finn, G.
1983: Geology, Mountaineer Lakes–East Red Wine Mountains area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 83-33.

Thomas, A., Nunn, G.A.G. and Krogh, T.E.
1986: The Labradorian Orogeny: evidence for a newly identified 1600 to 1700 Ma orogenic event in Grenville Province crystalline rocks from central Labrador. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A.J. Baer. Geological Association of Canada, Special Paper 31, pages 175-185.

Wardle, R.J. and Ash, C.
1984: Notes on the geology of the North West River area (13F/9) Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Notes to accompany Map 84-20, 8 pages.

1986: Geology of the Goose Bay–Goose River area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 113-122.

Wardle, R.J. and Crisby, L.V.J.
1986: Geology of the Goose Bay area. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File map 86-60.

1987: Geology of the Traverspine–McKenzie Rivers area (13F/1 and F/2). *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 201-209.

Wardle, R.J., Rivers, T., Gower, C.F., Nunn, G.A.G. and Thomas, A.
1986a: The northeastern Grenville Province: new insights. *In* The Grenville Province. *Edited by* J.M. Moore, A. Davidson and A.J. Baer. Geological Association of Canada, Special Paper 31, pages 13-29.

Wardle, R.J., Ryan, A.B., Ash, C. and Miller, H.G.
1986b: The Cape Caribou River Allochthon, Grenville Province, Labrador: structure and tectonic implications. Joint Annual Meeting. Geological Association of Canada, Mineralogical Association of Canada, Canadian Geophysical Union, Ottawa, 1986, Abstracts with Program, Volume 11, page 142.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 59-73

GEOLOGY OF THE ST LEWIS RIVER MAP REGION, GRENVILLE PROVINCE, EASTERN LABRADOR

Charles F. Gower, Timothy Van Nostrand and John Smyth
Labrador Mapping Section

ABSTRACT

The St Lewis River map region is subdivided into three structural–lithological entities, termed the Gilbert River shear belt, the Southwest Pond domain and the Pinware terrane. The Gilbert River shear belt consists of interfingering K-feldspar-megacrystic granitoid rocks, pelitic gneiss, the Alexis River anorthosite–leucogabbronorite and various dioritic, granodioritic and granitic orthogneisses (derived from the Alexis River anorthosite–leucogabbronorite and granitoid plutonic rocks). The Southwest Pond domain is underlain by pelitic gneiss intruded by K-feldspar-megacrystic- and nonmegacrystic-granitoid rocks and minor mafic plutonic rocks. It is bounded and transected by narrow zones of orthogneiss. The Pinware terrane is composed mostly of granitoid plutonic rocks associated with minor metasedimentary schist and gneiss, mafic plutonic rocks and orthogneiss. Granitoid rocks in the Pinware terrane are divided into three groups. Group I (syn-Labradorian?) consists of gneissic to moderately foliated rocks containing amphibolite enclaves interpreted as remnants of mafic dykes. Group II granitoid rocks (late-Labradorian or syn-Grenvillian?) lack amphibolite enclaves and are massive to weakly foliated. Group III comprises posttectonic plutons (late Grenvillian?). Post-Grenvillian units include redbeds of the Bateau Formation, basaltic flows of the Lighthouse Cove Formation, two suites of mafic dykes and huge north-northeast-trending quartz veins.

Thrusts and/or strike-slip faults bound each of the structural–lithological entities. The Gilbert River shear belt and the Southwest Pond domain are predominated by medium- to high-grade rocks having consistent west-northwest-trending structures partly related to the major zone of right-lateral displacement within the Gilbert River shear belt. The Pinware terrane is a region of less intense deformaton and metamorphism, in which west-northwest trends fade out progressively southward, and are replaced by less consistent directions interpreted to reflect emplacement of later granitoid plutons.

Targets for mineralization of economic interest include posttectonic granites and pegmatite, for potential incompatible element enrichment and muscovite respectively.

INTRODUCTION

Geological mapping at 1:100,000 scale of the St Lewis River map region in 1987 marks the fourth and final field season of a 5-year Canada–Newfoundland joint project, aimed at completing the mapping of an 80-km coastal fringe of the Grenville Province in southeastern Labrador. The St Lewis River map region comprises six NTS 1:50,000 scale map areas (3D/4, 5, 13A/1, 2, 7, 8), which collectively encompass a land area of approximately 5,000 km². Previous geological knowledge of the area is based mainly on descriptions of coastal localities (Lieber, 1860; Packard, 1891; Daly, 1902; Kranck, 1939; Christie, 1951; Douglas, 1953) and 1:500,000 scale reconnaissance mapping (Eade, 1962) and mineral exploration (Piloski, 1955) of the interior. More recently, complete aeromagnetic coverage and lake-sediment geochemical data have become available for the region (Geological Survey of Canada, 1974a, 1974b, 1984). The adjoining area to the north has been mapped by Gower *et al.* (1987) at 1:100,000 scale and that to the south at 1:125,000 scale by Bostock *et al.* (1983).

GENERAL GEOLOGY

Regional Setting

The region is situated entirely within the Grenville Province in southeastern Labrador (Figure 1). It is divided here into three lithostructural entities, named from north to south as follows: 1) Gilbert River shear belt, 2) Southwest Pond domain, and 3) Pinware terrane. The Gilbert River shear belt is a continuation of the same belt of rocks mapped in the Port Hope Simpson map region to the north (Gower *et al.*, 1987). The Southwest Pond domain also continues from the Port Hope Simpson map region, where it was previously unnamed. As Figure 1 of Gower *et al.* (1987) implied, the region may be a continuation of the Mealy Mountains terrane farther to the northwest, but until the intervening area is mapped this cannot be confirmed. The regional extent and significance of the newly defined Pinware terrane is uncertain, but regional gravity and aeromagnetic data suggest that it is probably distinct from the Mealy Mountains terrane; a speculative extrapolation of the boundary westward, based on geophysical data, is shown in Figure 1.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

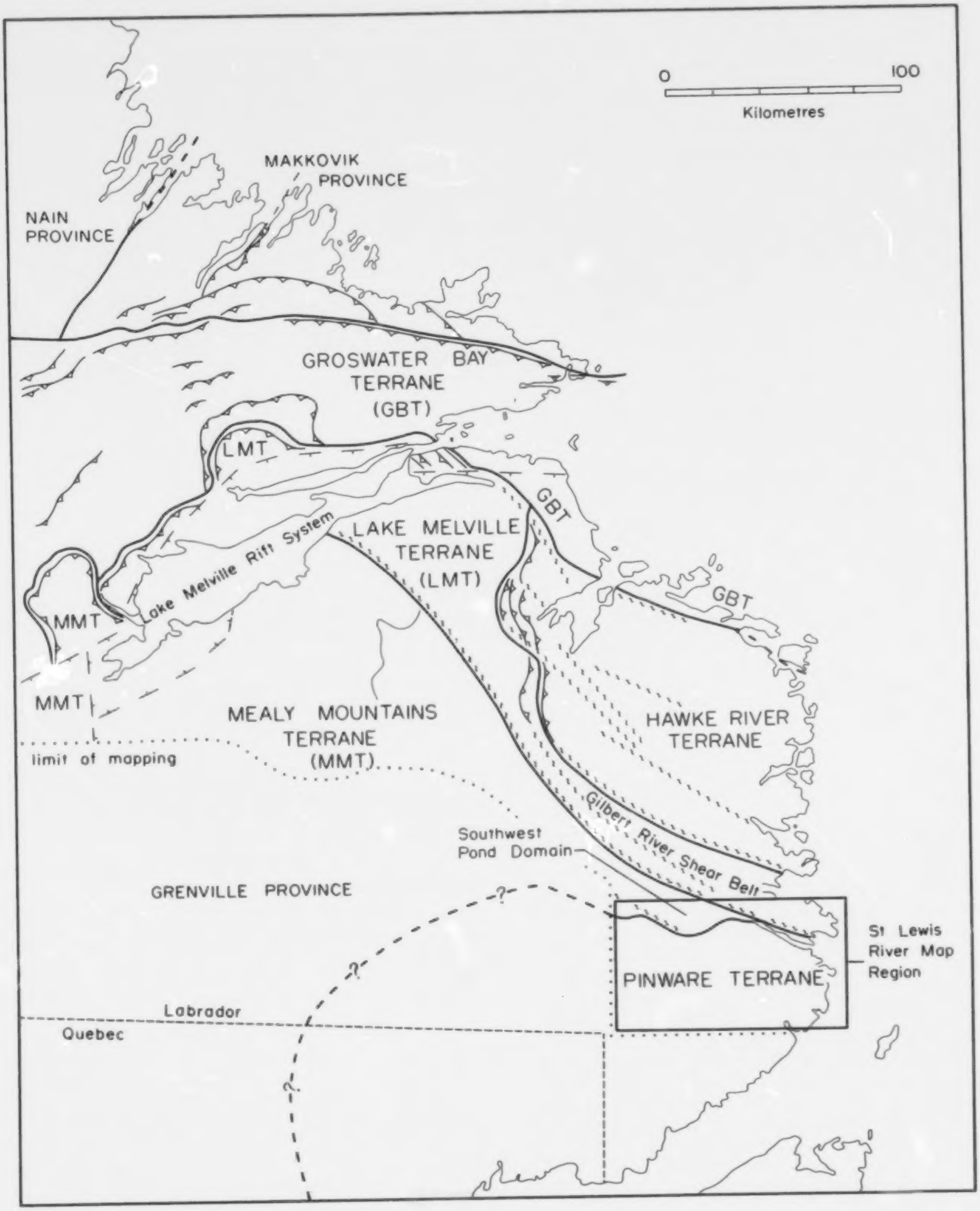

0
100
Kilometres
MAKKOVIK PROVINCE
NAIN PROVINCE
GROSWATER BAY TERRANE (GBT)
LMT
GBT
Lake Melville Rift System
LAKE MELVILLE TERRANE (LMT)
GBT
MMT
MMT
MEALY MOUNTAINS TERRANE (MMT)
HAWKE RIVER TERRANE
limit of mapping
Gilbert River Shear Belt
Southwest Pond Domain
GRENVILLE PROVINCE
?
?
?
PINWARE TERRANE
St Lewis River Map Region
Labrador
Quebec

Figure 1. *Structural subdivision of the Grenville Province in eastern Labrador and the location of the St Lewis River map region.*

No geochronological data are available within the study area. Regional geological relationships suggest that the earliest rocks probably have ages between 1700 Ma and 1650 Ma, and have been intruded by granitoid rocks associated with the Grenvillian Orogeny at ca. 1000 Ma. Outliers of Late Proterozoic to early Phanerozoic rocks are present in the southeast corner of the map region.

The 1:100,000 scale map, from which Figure 2 is simplified, is based on about 2000 data stations established during ground traverses spaced at 3- to 4-km intervals in the interior of the region, at spot helicopter landings in the intervening areas and during ground traverses along the coast. All samples have been slabbed and stained (potassium specific) and about 500 thin sections examined in a cursory manner.

Gilbert River Shear Belt

The Gilbert River shear belt is a zone of intense deformation about 30 km wide forming a southeasterly attenuated part of the Lake Melville terrane (Figure 1). Farther to the northwest, the equivalent zone of deformation marks the boundary between the Lake Melville and Mealy Mountains terranes, giving a total strike length of over 270 km for this shear belt.

Only a small portion of the Gilbert River shear belt is within the St Lewis River map region, where it underlies a triangular-shaped area in the northeast part of the area. Three distinct lithological zones are present. These are: 1) intermixed K-feldspar-megacrystic granitoid rocks, and (mainly) pelitic metasedimentary gneiss and orthogneiss on the northeast side, 2) a belt that includes the Alexis River anorthosite and its dioritic gneiss envelope, and 3) a narrow band of intermixed K-feldspar-megacrystic granitoid rocks, K-feldspar-augen gneiss and fine grained granitic gneiss on the southwest side. The first two of these lithological zones are direct continuations of those previously described from the Port Hope Simpson map region (Gower *et al.*, 1987).

Northeast side. The earliest rocks are metasedimentary gneisses. These are mostly pink and black, white, brown, grey or rusty-weathering, fine- to medium-grained, recrystallized, homogeneous to well-banded rocks. Banding results from alternation of leucosome and restite, intercalated amphibolitic layers and concordant minor granitoid intrusions. Some metasedimentary gneiss is gradational or interspersed with K-feldspar-megacrystic granitoid rocks.

The mineralogy of the pelitic gneiss comprises K-feldspar, plagioclase, quartz, biotite, sillimanite, garnet and opaque minerals. Garnet occurs as mauve to dark-red grains, in places up to 1 cm across, although most are commonly less than 2 mm in diameter. It is scattered throughout the gneiss or concentrated into distinct garnet- and biotite-rich (restite?) layers.

Associated metasedimentary rocks include quartzite, calc-silicate rocks and quartzofeldspathic gneiss, probably derived from an arenaceous protolith. These lithologies occur as grey- to green- or rusty-weathering pods or boudins within the pelitic gneiss and orthogneiss, and as enclaves in the surrounding megacrystic granitoid rocks. In places, boudins comprising mutually interlayered quartzite and calc-silicate rocks can be observed. The calc-silicate rocks contain diopside, hornblende, epidote, quartz, titanite, grossularite, plagioclase, phlogopitic mica, K-feldspar and carbonate. Minor thulite was noted in calc-silicate pods in the Mecklenburg Harbour area.

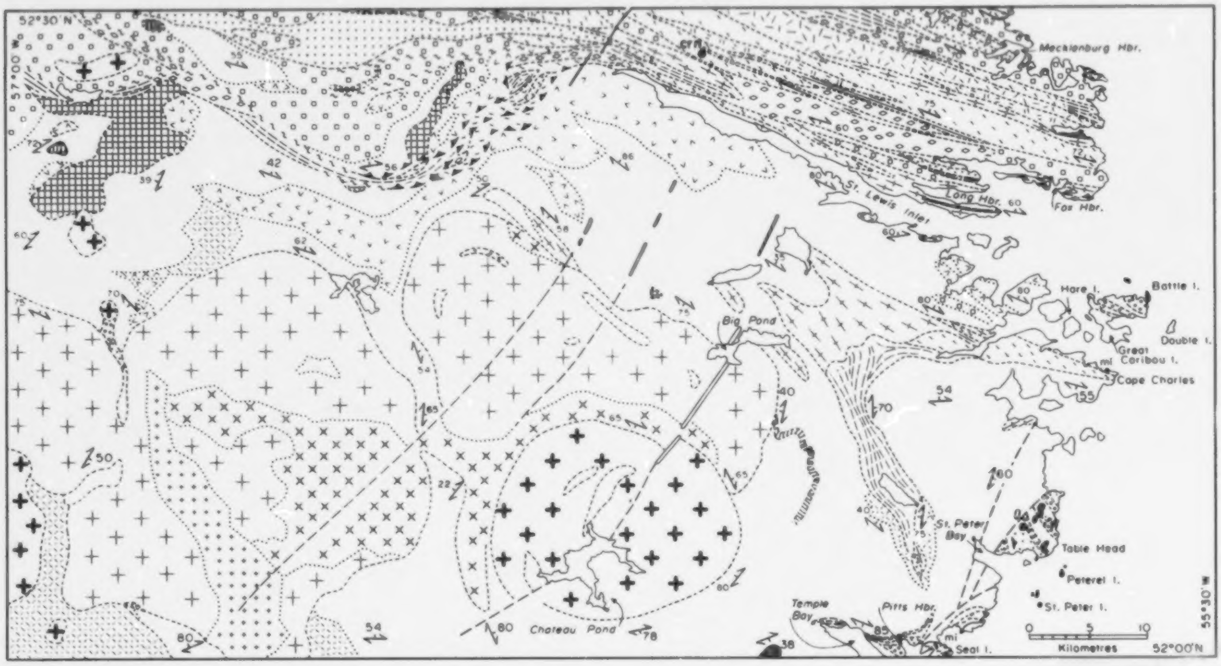
The K-feldspar-megacrystic granitoid rocks are grey, pink- or buff-weathering, fine- to coarse-grained rocks of granodiorite to quartz monzonite composition. Texturally, they vary from homogeneous, moderately foliated units to rocks that have been very strongly deformed and thoroughly migmatized. Although typically strongly deformed, megacrystic textures can be recognized and their granitoid origin inferred. The megacrysts form up to 30 percent of the rock, and range from 2 to 4 cm in diameter. Commonly they exhibit rounded, zoned, unrecrystallized cores and, irregular, recrystallized rims. The matrix consists of quartz, plagioclase, green biotite, minor garnet, allanite and opaque minerals. Seriate or equigranular textures give way to laminated rocks in zones of strong deformation, where recrystallization and grain-size reduction are extreme.

Enclaves within the megacrystic granitoid rocks include anorthosite (one locality), amphibolite and metasedimentary gneiss. The anorthosite is identical with the Alexis River anorthosite, from which we assume it to have been derived. The amphibolite enclaves, although consisting of recrystallized, polygonized minerals retain diabasic textures in places. They are interpreted as remnants of two suites of mafic dykes, emplaced prior to Labradorian deformation and metamorphism at ca. 1650 Ma (Gower *et al.*, 1987). Syntectonic and posttectonic pegmatite and microgranite are also associated with the K-feldspar-megacrystic granitoid unit.

Orthogneiss, associated with the above rock types, is minor. It includes granitic, granodioritic and dioritic types that have been fully described from the Port Hope Simpson map region (see Gower *et al.*, 1987). Isolated outcrops of mafic plutonic rocks, in the northeast part of the Gilbert River shear belt, are dark green- or brown-weathering, medium- to coarse-grained metagabbronorite having garnet and/or amphibole coronitic textures.

Central zone, including Alexis River anorthosite. This zone, including the Alexis River anorthosite and its (mainly) dioritic gneiss envelope, is 6 to 7 km wide in the St Lewis River map region, which is similar to that farther northwest, although the ratio of anorthosite to dioritic gneiss is lower in the St Lewis area. The borders of the zone are gradational and interdigitating with the surrounding more felsic gneiss.

The Alexis River anorthosite is a white, grey, brown or rusty-weathering, fine- to very coarse-grained rock, locally characterized by very pitted weathered surfaces. The anorthosite is gradational into leucogabbronorite. A complete


52°30'N
57°00'
Mecklenburg Hbr.
St. Lewis Inlet
Long Hbr.
Fox Hbr.
Hare I.
Battle I.
Double I.
Great Caribou I.
mi
Cape Charles
Big Pond
St. Peter Bay
Table Head
Peterel I.
St. Peter I.
Temple Bay
Pitts Hbr.
Seal I.
Chateau Pond
0 5 10
Kilometres
52°00'N
55°30'W

LEGEND

UPPER PRECAMBRIAN–LOWER PALEOZOIC

- ▨ *Gabbro, diabase (solid); quartz veins (open)*
- ● *Bateau and Lighthouse Cove formations*

UPPER PROTEROZOIC
Group III granitoid rocks

- ✚ *Massive, coarse grained granite (late-Grenvillian)*

UPPER OR MIDDLE PROTEROZOIC
Group II granitoid rocks

- × *Syenite, quartz syenite, alkali-feldspar granite*
- + *Coarse grained granite, alkali-feldspar granite*
- ∴ *Fine grained granite, alkali-feldspar granite*

MIDDLE OR LOWER PROTEROZOIC
Group I granitoid rocks

- ▒ *Syenite, quartz syenite*
- ☐ *Biotite granite, alkali-feldspar granite*
- ○ *K-feldspar-megacrystic granitoid rocks*
- ˅ *Hornblende–biotite quartz monzonite–diorite*

Unassigned mafic plutonic rocks

- ▦ *Gabbro, norite, websterite*

Alexis River anorthosite

- ⁄ *Anorthosite–leucogabbro–norite*
- ≈ *Gabbronorite and associated ultramafic rocks*

MIDDLE OR LOWER PROTEROZOIC
(continued)

Metasedimentary gneiss

- ⁝ *Sillimanite–K-feldspar pelitic gneiss and muscovite schist*
- ∵ *Banded (bedded?) quartzofeldspathic rocks; volcanoclastic?*
- ∿ *Quartzite, commonly associated with calc-silicate rocks*

Orthogneiss

- ■ *Schistose epidote-rich amphibolite, possibly supracrustal*
- ⟋ *Biotite granite gneiss*
- ⟍ *Biotite granodiorite gneiss*
- ⁞ *Biotite–hornblende diorite to quartz diorite gneiss*
- ○ *K-feldspar augen gneiss*

SYMBOLS

- - - -······ *Geological boundary; approximate, diffuse*
- ⌄⌄⌄⌄⌄ *Undifferentiated faults, mostly strike slip*
- —— —— *Normal faults*
- ⇀ 35 *Gneissosity, foliation*
- mi • *Muscovite prospect*
- crn • *Corundum locality*

Figure 2. *Geology of the St Lewis River map region.*

spectrum exists from weakly deformed rocks that retain primary mineralogy, texture and structure (including layering) to intensely deformed mylonitic or gneissic units. The most characteristic lithology is a white, sugary-textured, fine grained, strongly foliated and recrystallized plagioclase-rich rock, in which the mafic silicates occur as lenses or streaked-out aggregates.

In those rocks containing primary minerals, purplish-grey plagioclase (An_{57} at a spot determination) occurs with rusty-brown orthopyroxene and grey-green clinopyroxene. These relict grains are commonly enveloped in recrystallized aggregates of the same mineral, or are mantled by amphibole and/or garnet coronas. Garnet also occurs as discrete euhedral and anhedral porphyroblasts, locally as large as 3 cm. The rocks are, in places, veined by secondary prehnite.

Closely associated with the leucogabbronorite are more melanocratic rock types that include mesogabbronorite and ultramafic units. The largest of these are shown separately from the anorthosite in Figure 2. They are grey-green, medium- to coarse-grained, massive to schistose rocks consisting dominantly of amphibole, with lesser orthopyroxene, clinopyroxene, garnet, plagioclase and opaque minerals. The close spatial association with the anorthositic rocks clearly indicates that they were once part of the same layered intrusion. Mappable units (at 1:100,000 scale) of both anorthositic and melanocratic types, extending for several kilometres along strike, occur within the dioritic gneiss envelope separate from the large areas, but are too narrow to be indicated in Figure 2.

The orthogneiss envelope to the Alexis River anorthosite is dominated by dioritic gneiss, with lesser amphibolitic, granodioritic, augen granodioritic, monzonitic and granitic variants. The dioritic gneiss is a grey- to rusty-white-weathering, fine- to coarse-grained rock having a discontinuous banding emphasized by layers of concordant amphibolite, leucosome and minor granitoid intrusions. It consists of hornblende and plagioclase associated with minor clinopyroxene, garnet, quartz, K-feldspar and opaque minerals. Amphibolitic gneiss is similarly banded, but may contain vestiges of primary igneous plutonic layering. The felsic orthogneisses are generally medium grained, creamy, buff or pink migmatitic rocks derived almost certainly from tectonic interleaving of metamorphic derivatives of the anorthositic package with the surrounding granitoid intrusions.

An outcrop of metasedimentary gneiss included within the anorthosite–dioritic gneiss deserves special mention. At this locality there are schists containing abundant muscovite, mauve garnet and K-feldspar porphyroblasts. These are interlayered with zones containing abundant sillimanite and garnet, quartzite layers containing large purple garnet, some biotite-rich schlieren and concordant layers of amphibolite. In addition, there is a very distinctive rock containing plagioclase (An_{48}), red-brown biotite and large blue corundum porphyroblasts as large as 2.5 cm across and several centimetres long (Plate 1). We interpret the corundum-bearing rock to be a metasomatized anorthosite.

Plate 1. *Corundum porphyroblasts (arrowed) in plagioclase-rich rock (metasomatized anorthosite?) associated with pelitic gneiss in outcrop; Gilbert River shear belt.*

Southwest side. The K-feldspar-megacrystic granitoid rocks, K-feldspar-augen gneiss and granitic gneiss on the southwest side of the Gilbert River shear belt form a zone of tectonically interleaved units varying from homogeneous rocks to well-banded gneiss and migmatite. The rocks are pink, buff, grey or creamy weathering, fine to medium grained and consist of quartz, microcline, plagioclase, biotite, opaque minerals, titanite, allanite, apatite and epidote. The common occurrence of titanite and epidote distinguishes these units from the granitoid rocks north of the Alexis River anorthosite. In the K-feldspar-megacrystic granitoid rocks, the megacrysts comprise as much as 25 percent of the rock and may be as large as 3 cm in diameter. The augen gneiss differs mainly in intensity of deformation and extent of migmatization, and can be interpreted as the tectonized equivalent of the megacrystic granitoid rocks.

The associated fine- to medium-grained granitic gneiss is comparable to that described by Gower *et al.* (1987) from the Port Hope Simpson map region. The most probable protolith is either granitoid plutonic rocks or psammitic metasediment, but extreme recrystallization and grain-size reduction renders unequivocal identification impossible. The description and discussion of the granitic gneiss in the Port Hope Simpson map region applies equally well to similar lithologies in the St Lewis River map region and the reader is referred to Gower *et al.* (1987) for further details.

Southwest Pond Domain

The Southwest Pond domain comprises metasedimentary gneiss associated with granitoid plutonic rocks, subsidiary mafic plutonic bodies and minor orthogneiss. The domain is distinguished from the Gilbert River shear belt by the less intense deformation (except flanking the north side of St Lewis Inlet), and from the Pinware terrane by higher metamorphic grade.

Most of the pelitic metasedimentary gneiss is contained within a single, east-southeast-tapering unit. The maximum width is about 5 km, considerably reduced from the 15 km in the Port Hope Simpson map region, immediately to the northwest. At its eastern end the metasedimentary gneiss merges into fine grained granitic gneiss, which in part may represent a psammitic equivalent, although no diagnostic metasedimentary gneiss features are retained. A tectonic sliver of metasedimentary gneiss north of Long Harbour is interpreted as the discontinuous strike extension of the same unit.

The pelitic gneiss is a creamy-, buff-, grey- or rusty-weathering, fine- to medium-grained rock showing nebulitic, schlieric or well-banded fabrics. Locally it grades into metasedimentary diatexite consisting of wispy biotite-rich schlieren and inhomogeneous pegmatoid patches. The mineralogy comprises quartz, plagioclase, K-feldspar, biotite, sillimanite, garnet, apatite and opaque minerals. Garnet is locally retrograded to plagioclase and biotite. Hornblende-bearing layers and enclaves of amphibolite occur in many outcrops and minor granitoid intrusions are ubiquitous. Metasedimentary gneiss north of Long Harbour contrasts in being a white- to grey-weathering, fine grained, strongly recrystallized, biotite–muscovite–plagioclase–quartz schist. Muscovite is interpreted as a retrograde product formed during shearing associated with the Gilbert River shear belt.

Distinctive calcareous quartzite and calc-silicate rocks south of Long Harbour, on Battle Island and on Great Caribou Island are also described in this section, although their tectonic affinity with the Southwest Pond domain is not certain. Quartzite, south of Long Harbour, forms a distinctive unit of grey- to white-weathering, medium grained rock and was previously mapped by Christie (1951). The extrapolation of this unit westward from the coast is based on Christie's map, as it was only examined on the shoreline during this study. It seems likely, as suggested by Christie, that the quartzite south of Long Harbour is the lateral equivalent of quartzite on Battle Island, first described by Kranck (1939). The superbly exposed Battle Island quartzite is grey, white or maroon (where hematized) weathering, medium grained and exhibits both parallel lamination and crossbedding (Plate 2). A primary sedimentary origin for the crossbedding noted previously by Kranck (1939) is not in doubt and the unit consistently gives west facing. These quartz-rich rocks also contain plagioclase, microcline, biotite, amphibole, titanite, epidote, carbonate and opaque minerals. A distinctive feature is the presence of amphibole porphyroblasts, up to about 1 cm across, surrounded by halos depleted in mafic silicates.

The presence of Ca-bearing silicates in the quartzite is easily understood in terms of their close association with calc-silicate rocks. Excellent exposures of the latter are present at the north end of Battle Island (Plate 3), where they consist of grey-green-weathering, medium grained, well-banded, diopside–plagioclase–epidote–carbonate rocks, interbedded with quartzofeldspathic and amphibolitic layers (see also descriptions by Kranck, 1939 and Christie, 1951). Similar quartzite and calc-silicate rocks form small islands northwest of Battle Island.

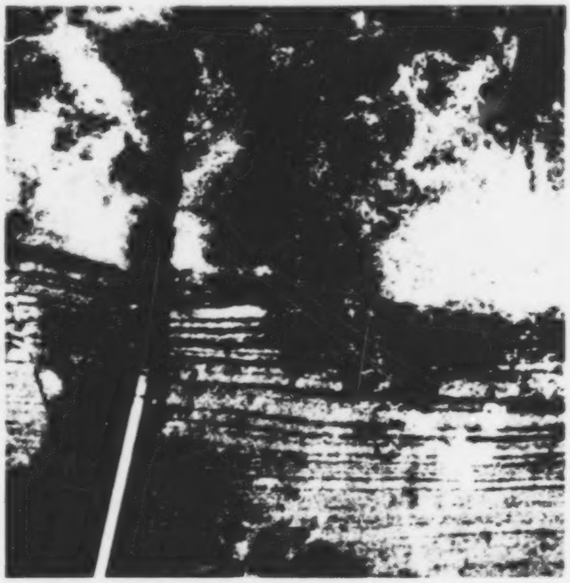


Plate 2. *Crossbedded quartzite; Battle Island.*

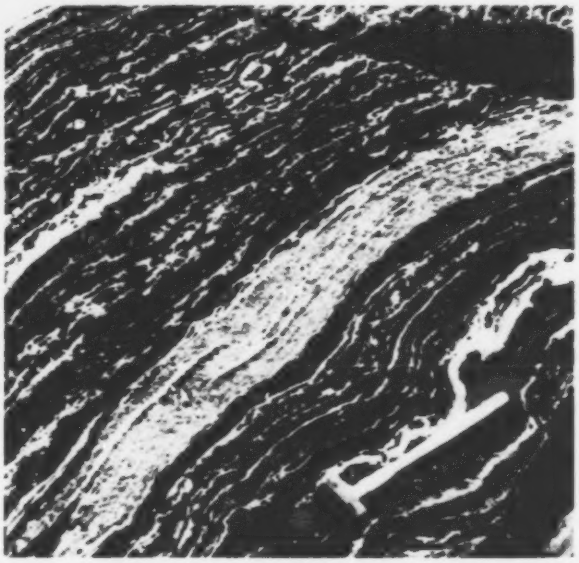


Plate 3. *Well-bedded calc-silicate rocks; Battle Island.*

A similar assemblage is present on the northeastern half of neighbouring Great Caribou Island, where they are associated with maroon, yellow and white-weathering, medium grained, arkosic units. Some layers are deformed conglomerate or felsic agglomerate, as indicated by ellipsoidal clasts having a wide range of quartzofeldspathic compositions (Plate 4). These clasts, coupled with the crossbedded quartzite, makes the Battle Island area unique in the Grenville Province of eastern Labrador, in being the only area where unequivocal features demonstrating a supracrustal origin, are preserved. The agglomerate–conglomerate contains abundant carbonate as a matrix mineral and is interbedded with thinly laminated quartz-rich metasediment. Both Battle Island and the northeast corner of Great Caribou Island are pervasively intruded by large pegmatite dykes (in places over 10 m wide) containing common muscovite and magnetite.

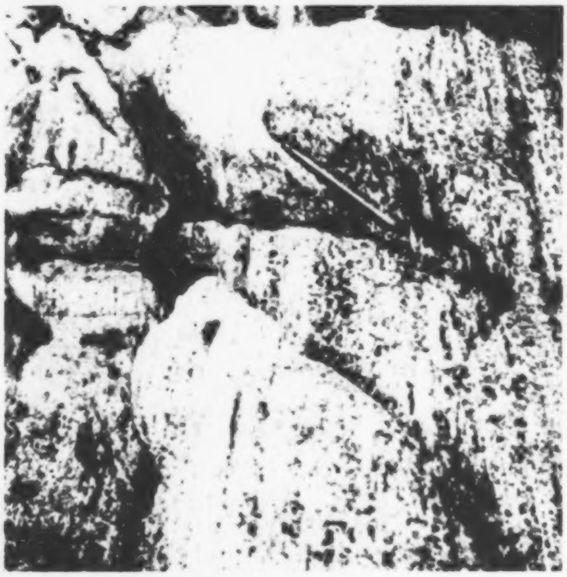


Plate 4. *Deformed conglomerate or felsic agglomerate containing ellipsoidal clasts of various compositions; eastern Great Caribou Island.*

Granitoid rocks in the Southwest Pond domain include quartz diorite, quartz monzonite, granodiorite, granite and K-feldspar-megacrystic variants. K-feldspar-megacrystic granodiorite is most common, forming ovoid (in plan) plutons intruding metasedimentary gneiss, and irregularly shaped bodies associated with other granitoid units. These buff, honey, white and pink-weathering, medium grained rocks have fabrics that grade from massive or weakly foliated to gneissic or mylonitized. K-feldspar megacrysts typically measure 2 cm by 2 cm and constitute 10 to 20 percent of the rock. In places, these rocks grade into nonmegacrystic variants with otherwise similar characteristics. The mineralogy is quartz, plagioclase, microcline, biotite, minor hornblende, allanite, titanite, apatite, opaque minerals and garnet.

Quartz diorite, quartz monzonite and granite in the Southwest Pond domain are melanocratic and leucocratic variants of the same suite of granitoid rocks. The quartz diorite–monzonite is a black and creamy- or grey-weathering, medium- to coarse-grained rock, having weak to strong foliation and grading locally into gneiss. The mineralogy comprises quartz, plagioclase, microcline, hornblende, biotite, titanite, allanite and opaque minerals. The granite differs mainly in weathering colour (being pink or white) and mineralogy, lacking hornblende and containing more quartz and K-feldspar. All the granitoid rocks in the Southwest Pond domain are characterized by mafic enclaves, ranging from amphibolite layers as wide as 5 m to biotitic schlieren only 1 to 2 cm across. Concordant and discordant pegmatite and microgranite veins and dykes are ubiquitous.

Mafic plutonic rocks in the Southwest Pond domain occur as isolated outcrops and more extensive sill-like bodies. They are green-black, dark grey- and rusty-weathering, medium grained rocks, typically massive to weakly foliated; rock types range from leucogabbro to ultramafite. The mineralogy consists of olivine, orthopyroxene, clinopyroxene, amphibole, plagioclase, opaque minerals, green spinel and garnet. Coronitic textures are present in places. In part, these minerals are relict primary grains; elsewhere they are granoblastic metamorphic aggregates.

Orthogneiss is confined to the borders of the Southwest Pond domain, and to narrow shear zones within it (Plate 5). A wide range of compositions is present, including diorite, granodiorite, megacrystic granodiorite and granite. The rocks are similar to those described from the Gilbert River shear belt, and, likewise, can be interpreted as severely deformed and migmatized plutonic intrusions. In several places, but especially in the zone of southeast-directed thrusts (Figure 2), the gneisses are very fine grained, laminated mylonites showing prominent linear fabrics.

Plate 5. *Isoclinally folded dioritic orthogneiss associated with southeast-directed thrusts bounding the south side of the Southwest Pond domain, St Lewis River. Notebook is 11 cm wide.*

A small body of granite in the western part of the Southwest Pond domain contrasts from the other units in the domain in that it is a massive to weakly foliated, pale grey- to pink-weathering, homogeneous, medium grained, muscovite biotite granite. It also contains enclaves of more strongly foliated granitoid rocks and, hence, we interpret it to be a younger granite intrusion, possibly postdating Grenvillian orogenesis. It is possible that several closely grouped smaller bodies are present, rather than the single intrusion depicted.

Pinware Terrane

The Pinware terrane is a newly defined region that underlies the southern 80 percent of the St Lewis River map region. It contrasts from other terranes in eastern Labrador by its lithological homogeneity, being composed principally of granitoid plutonic rocks. This lack of diversity invites comparison with the Grenvillian Long Range Inlier in Newfoundland, mapped and described by Erdmer (1986) and Owen *et al.* (1987). The main components are metasedimentary gneiss, orthogneiss, mafic plutonic rocks and granitoid plutonic rocks.

Metasedimentary gneiss is areally insignificant, probably underlying less than 1 percent of the Pinware terrane. The writers discovered two localities in the western part of the map region; a group of quartzite−calc-silicate rocks occur south of Big Pond, and more extensive rocks of probable metasedimentary origin were seen on the coast. The two outcrops in the west both have pelitic and psammitic components. The pelitic rocks are white- to pale pink-weathering, medium grained rocks having discontinuous to continuous banded fabrics. The mineralogy is quartz, plagioclase, K-feldspar, biotite, sillimanite, garnet and opaque minerals. The locality in the southwest corner of the map region also contains serpentine pseudomorphs, possibly after cordierite. The psammitic gneiss comprises quartz, plagioclase, K-feldspar, biotite, garnet and opaque minerals and lacks diagnostic metasedimentary features. It is noteworthy that Bostock *et al.* (1983) recorded sillimanite-bearing pelitic gneiss, locally associated with calc-silicate rocks at a few localities southeast of, and roughly on strike with the outcrop in the southwest corner of the St Lewis River map region. They did not attempt to show the regional extent of areas underlain by metasedimentary gneiss.

Quartzite mapped south of Big Pond is a laminated, white- or grey-weathering, fine- to medium-grained rock consisting of quartz with minor amounts of plagioclase, clinopyroxene, amphibole, clinozoisite or opaque minerals. It is associated with calc-silicate rocks and some banded amphibolite. The mineralogy of the calc-silicate rocks includes clinopyroxene, quartz, plagioclase, carbonate and opaque minerals. Most of the outcrops are small and isolated; linking them into the single sinuous layer indicated on the map is somewhat speculative.

Presumed metasedimentary rocks in the southeast coastal part of the Pinware terrane, can be divided into muscovite schists and compositionally layered quartzofeldspathic rocks. The muscovite schists are grey-, white- or creamy-weathering, fine- to medium-grained rocks, consisting of quartz, K-feldspar, plagioclase, biotite, muscovite, garnet and accessory phases. Schistose zones containing abundant muscovite alternate with broader, more homogeneous layers. It seems likely that these rocks were derived from an argillaceous or fine grained pyroclastic protolith. The quartzofeldspathic rocks show very pronounced layering (bedding?) defined by colour (maroon, cream, white, grey, and purple), grain size and composition (Plate 6). Commonly the rocks contain amphibole porphyroblasts and have K-feldspar-rich segregations. One rock contains abundant, strongly pleochroic (lilac to dark blue-green) amphibole, and is probably sodic in composition. This rock also contains corundum and a serpentine pseudomorph, possibly after orthopyroxene. The rocks lack garnet or aluminosilicates. Texturally, the rocks are completely recrystallized and show no diagnostic fabrics pertinent to inferring their protolith. The distinctive layering, anomalous mineralogy and association with muscovite schists suggest a supracrustal origin, possibly an arenaceous or felsic volcanic protolith. Comparable rocks occur on Great Caribou Island, broadly associated with quartzite and calc-silicate units.

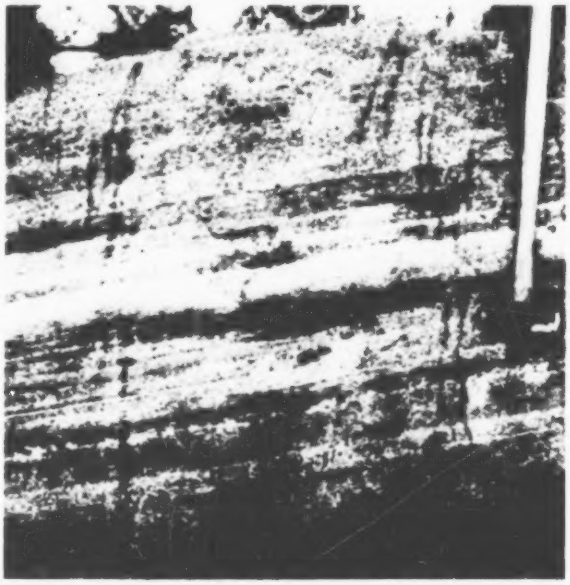


Plate 6. *Compositionall banded (bedded?) quartofeldspathic rock, possibly derived from an arenaceous or volcanoclastic protolith; west of Table Head.*

Isolated outcrops of orthogneiss occur throughout the Pinware terrane, but it is extensive only in the eastern part of the region. The area defined by Cape Charles, Big Pond and Pitts Harbour is underlain by dioritic, granodioritic, granitic and amphibolitic gneiss. The dioritic gneiss consists of pink-, creamy- or grey-weathering, medium- to coarse-grained, hornblende quartz diorite to monzonite having irregular quartzofeldspathic leucosome segregations. It is found with migmatized amphibolite and intruded by granitic veins. On the coast, these rocks are interlayered with broader, concordant zones of granite. The granodioritic gneiss grades from relatively homogeneous units containing mafic enclaves or boudinaged dykes to well-banded, migmatitic rocks. The granitic gneiss is similar in appearance, differing only in bulk composition. Some granitic gneiss displays well-defined, regular layers, suggestive of a metasedimentary protolith. It is noteworthy, in this regard, that muscovite schist is present in the southern tip of the Big Pond–Temple Bay orthogneiss belt. Orthogneiss in the southeast Pinware terrane lacks the strongly foliated, well-banded and thoroughly migmatized appearance of the orthogneiss farther north. Instead, they appear to be the result of multiple injection of various granitoid and mafic dyke phases, onto which deformaton has been superimposed to give a banded rock.

The belt of orthogneiss extending southward from Big Pond can be conceptually linked with gneiss in the Pitts Harbour–Temple Bay area. These rocks are indicated as granodioritic orthogneiss in Figure 2, but also include syenitic and monzonitic variants. Further extrapolation of the gneiss westward suggests a link with fine grained, schistose, laminated amphibolite at the southern boundary of the map region. The amphibolite is distinctive in that it contains acicular amphibole and abundant epidote and titanite; it may be supracrustal in origin. Bostock *et al.* (1983) have mapped more extensive amphibolite southwest of, and on strike with this locality. Orthogneiss was also mapped east of Pitts Harbour, intercalated with gneiss of probable metasedimentary origin. These gneisses include dioritic, granodioritic, syenitic and granitic varieties, associated with broad amphibolite layers and abundant pegmatite.

Mafic plutonic rocks are a minor component of the Pinware terrane, and only one extensive body is present. This is in the northwest part of the terrane and consists of grey-, brown-, purple- or buff-weathering, medium- to coarse-grained gabbronorite, gabbro, leucogabbro, diorite and monzogabbro, all of which are extensively modified by metamorphism. Primary pyroxene and plagioclase occur as relict grains enveloped in recrystallized mosaics, or surrounded by amphibole–spinel coronas. Most of the leucocratic rock types are in the southern arm of the body. Scattered outcrops of mafic plutonic rocks elsewhere include metamorphosed pyroxenite, gabbronorite, websterite and gabbro, and occur mostly in the northern half of the Pinware terrane.

Granitoid rocks of the Pinware terrane can be divided into three groups. Group I consists of moderately foliated to gneissic granitoid rocks having common amphibolite enclaves. Group II granitoid rocks are massive to weakly foliated and lack amphibolite enclaves. Group III comprises posttectonic plutons. No age data are available for any of these groups, but as a working hypothesis, we consider the first group to have been emplaced synchronously with the Labradorian Orogeny (1.65 Ga); the second group to be either late-Labradorian or syn-Grenvillian: and the third group to postdate the Grenvillian Orogeny (1.0 Ga).

Group I granitoid rocks. Granitoid rocks in the first group include granite *sensu stricto,* (which is the most abundant rock type), quartz syenite to alkali feldspar granite, quartz monzonite to quartz diorite and K-feldspar-megacrystic variants. The granite weathers pink, grey, buff, white or rusty, and commonly has a characteristic, streaky pink and white appearance. Grain size varies from fine to coarse, and the rocks have recrystallized, seriate, homogeneous or nebulitic textures. A separate leucosome component is normally absent, but some rocks do show diffuse patches or layers enriched in K-feldspar. The mineralogy comprises quartz, K-feldspar, plagioclase, biotite, apatite, allanite, titanite, opaque minerals and sporadic clinopyroxene or amphibole. Titanite is a ubiquitous and unusually abundant accessory mineral in most granitoid rocks in the Pinware terrane.

The granites show considerable variation in mineralogy and texture and probably include rocks emplaced over an extended period. Deformational histories of two granites exposed on the coast are instructive. Granite in St Peter Bay was intruded by mafic dykes, then microgranite and pegmatite and subsequently deformed twice. During the second deformation, axial planar segregations developed and were then crosscut by pegmatite. The late-stage history includes local shearing, further pegmatite injection, and hematite alteration along late-stage fractures. Granite south of Cape Charles contains elongate enclaves of banded quartzofeldspathic rock, possibly derived from a supracrustal protolith. The enclaves were deformed and migmatized prior to intrusion by mafic dykes and subsequent inclusion in the granite. Deformation of the granite was followed by pegmatite injection, intrusion of a distinctive buff-coloured microgranite, and finally brittle faulting. Combining the histories of these two areas leads to the simplest conclusion that there were either two periods of mafic dyking (if the granites correlate), or that there were two periods of granite emplacement (if the mafic dykes correlate). Good geochronological evidence exists for both alternatives farther north. Samples have been collected from the two granites for dating.

Group I quartz syenite to alkali feldspar granite is most common in the western half of the Pinware terrane, especially in the southwest corner of the map region. The rocks are pink, buff or white weathering, medium to coarse grained, generally homogeneous and moderately foliated. Minerals include perthitic K-feldspar, lesser quartz and plagioclase and minor biotite, amphibole, clinopyroxene and magnetite. It is possible that some of this unit should be included with Group II granitoid rocks.

Quartz diorite–monzonite is mostly present in a somewhat sinuous, elongate belt in the central-north part of the Pinware terrane. Smaller bodies were mapped on the south side of the St Lewis Inlet and on islands farther east; these are on strike with the main belt and could be genetically related. The rocks are grey, brown, white or creamy weathering, fine to coarse grained, and show moderately foliated to locally gneissic fabrics. Leucosome partings occur in rocks close to the northern boundary of the Pinware terrane. The mineralogy is plagioclase, quartz, microcline, biotite, amphibole (soda rich in places), apatite, titanite, zircon, clinopyroxene and opaque minerals. The amphibole is commonly extensively altered to an orange-brown phyllosilicate.

K-feldspar-megacrystic granitoid rocks are notoriously sparse in the Pinware terrane, and are found mostly near its northern boundary. The rocks have limited areal extent and commonly have gradational boundaries with seriate-textured or nonmegacrystic units. The rocks are pink to grey weathering, medium to coarse grained, typically moderate to strongly foliated and extensively recrystallized. The fabric can be attributed to proximity to the more strongly deformed northern boundary of the Pinware terrane.

Amphibolites associated with Group I granitoid rocks are black, dark grey- or green-weathering, medium grained rocks that occur in bodies ranging in size from a few centimetres to units over 10 m wide. At one locality two contrasting types occur together. The earlier amphibolite is tightly folded and migmatized, in contrast to the later amphibolite, which is homogeneous and less deformed. We interpret amphibolite in the Pinware terrane as metamorphosed mafic dykes, and suggest that at least two suites are present. These were emplaced prior to the main and late deformations, respectively, that affected the host granitoid rocks.

Group II granitoid rocks. These rocks comprise two main rock types, namely 1) granite and 2) alkali feldspar granite to quartz syenite. Both types are pink, white, buff or creamy weathering, medium to coarse grained and have a homogeneous, massive to weakly foliated appearance. Stronger foliations are apparent in rocks adjacent to the Group III Chateau Pond granite. No leucosome component or migmatitic textures are evident. The mineralogy comprises perthite–microcline, plagioclase, quartz, biotite, minor amphibole, titanite, allanite, apatite, zircon and magnetite. The plagioclase content is very low in some rocks and the proportion of accessory minerals very high. Enriched rare-earth element patterns can be anticipated.

Although amphibolite is absent from these rocks they are not devoid of enclaves. These include amphibole- or biotite-rich schlieren and granitoid enclaves lithologically comparable to Group I units. The arrangement of enclaves near the northern margin of the eastern lobe suggests a concentric structure of some type. Foliation directions in the host granite follow the trend of the enclaves.

An elongate area of finer grained granite has been mapped in the western lobe. This could be a Group I unit, but it could also represent a border, or infolded roof zone of a Group II granite.

Group III granitoid rocks. Group III granitoid rocks include the Chateau Pond granite, the eastern margin of a slightly smaller pluton on the western margin of the study area, and scattered smaller intrusions. Similar plutons occur throughout southern Labrador and eastern Quebec and are characterized by doughnut-form aeromagnetic anomalies having magnetically high rims and low interiors. A monzonite from the centre of one such anomaly, immediately west of the St Lewis River map region, has yielded a U–Pb zircon age of 966 ± 3 Ma (Gower and Loveridge, 1987). In the St Lewis River map region, the Chateau Pond granite is the clearest example of a pluton belonging to this group (Plate 7). It is circular in outline and its emplacement has imparted a pronounced foliation to the surrounding rocks parallel to the margin of the pluton. The granite is pink to white weathering, coarse to very coarse grained, massive and homogeneous. K-feldspar occurs in grains up to 3.5 cm across. The mineralogy is perthite–microcline, quartz, sericitized plagioclase, chloritized green biotite, titanite, apatite, allanite, zircon and opaque minerals. The pluton lacks minor granitoid dykes and does not contain mafic enclaves or dykes. Large rafts of foliated biotite granite (Group I) are present and are probably more common than indicated in Figure 2.

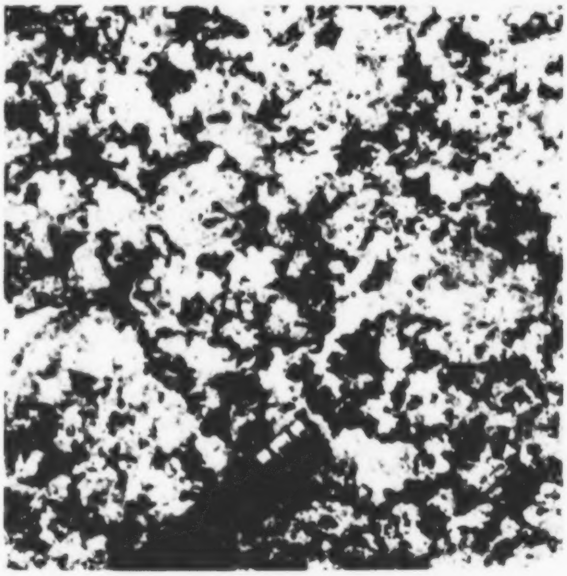


Plate 7. *Chateau Pond granite; Chateau Pond area.*

The granite on the western margin of the area is pink to rusty weathering, medium to coarse grained and massive to weakly foliated. It contains perthite, quartz, biotite, hornblende, clinopyroxene, zircon, magnetite and minor epidote. The common occurrence of clinopyroxene is a notable feature of this pluton. The smaller bodies are all pink, medium- to coarse-grained biotite granite. Their limited extent makes their classification as Group III intrusions equivocal.

Bateau Formation

Orange-, red- and maroon-weathering conglomerate, pebbly sandstone and arkose that uncomformably overlies

Grenvillian basement and underlies columnar-jointed basalt is correlated here with the Bateau Formation of Williams and Stevens (1969). These rocks are found on St Peter Islands, Peterel Islands, Table Head and several outliers northwest of Table Head. The present distribution of the Bateau Formation appears to be restricted to the west by a northeast-trending fault.

Talus from the overlying basalt prevents accurate measurement of section thickness at Table Head and the outliers to the northwest. The maximum thickness is probably about 10 m. On one of the western islands in the St Peter Islands group, an almost complete 5-m section of Bateau red arkose and conglomerate is exposed. On the most southerly of the St Peter Islands, the unit has a maximum thickness of 30 cm. In general, there appears to be a southeasterly thinning of the unit.

The arkose includes both parallel lamination and crossbedded layers, which have master bedding planes, up to 30 cm apart, defined by colour, grain-size variation and heavy-mineral laminae (Plate 8). The conglomeratic layers contain pebbles of quartz, granite and pegmatite derived from the underlying quartzofeldspathic basement. Basement relationships are well exposed on the most southerly of the St Peter Islands where pegmatite intruding basement amphibolite is unconformably overlain by basalt of the Lighthouse Cove Formation. The base of the basalt is marked by a breccia layer, between 2 to 30 cm thick, formed from the basement regolith that includes clasts of pegmatite, intermixed with scoriaceous material from the flow.

In thin section, the arkose is seen to consist of grains of quartzofeldspathic rock associated with smaller particles of quartz, feldspar, phyllosilicates and opaque minerals. These are contained within a carbonate–hematite cement.

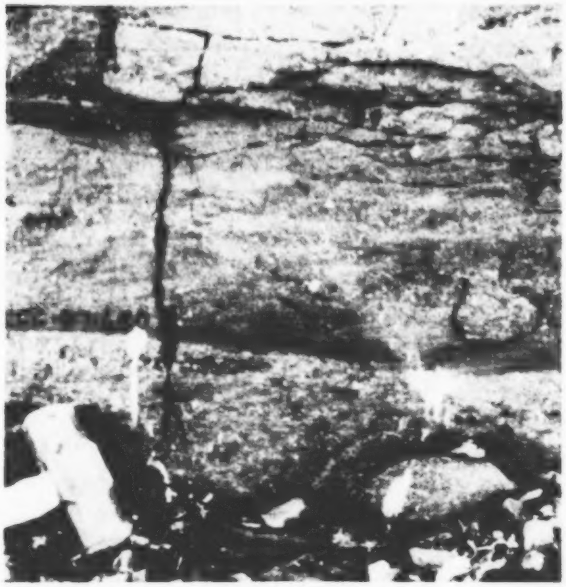


Plate 8. *Crossbedded arkose of Bateau Formation; St Peter Islands.*

A clastic dyke, assumed to correlate with the Bateau Formation, was discovered on Great Caribou Island. It is 30- to 50-cm wide and is made up of two parts. The older part is a conglomerate–breccia containing fragments of K-feldspar and quartzofeldspathic rocks. This is cut by a maroon sandstone dyke containing fragments of the earlier breccia in a matrix of carbonate, hematite, quartz and feldspar.

Lighthouse Cove Formation

Basalt overlying the Bateau Formation is correlated with the Lighthouse Cove Formation (Williams and Stevens, 1969; Strong and Williams, 1972). The thickest section is on the St Peter Islands, where about 15 m of basalt is exposed (Plate 9). At Table Head and the other mainland outliers, the sections are less than 10 m thick. No rocks overlie the basalt and the uppermost parts of the basalt have been removed by erosion in all areas, hence the original thickness is unknown.

Plate 9. *Unconformity between Grenvillian basement and overlying Lighthouse Cove Formation–the basement rocks comprise amphibolite intruded by deformed pegmatite dykes; St Peter Islands.*

On the St Peter Islands, the basalt can be divided into a lower columnar-jointed part and an upper, hackly fractured part, similar to that present at Henley Harbour (immediately south of the St Lewis River map region), and described by Bostock *et al.* (1983). The basalts are brown to grey weathering, locally with green or maroon hues and are plagioclase- or pyroxene-porphyritic and amygdaloidal in places. The amygdules are pink near the base of the flows, but black farther up.

No pegmatite or mafic dykes were seen to intrude either the Bateau or Lighthouse Cove formations.

Upper Precambrian–Lower Palaeozoic Mafic Dykes and Quartz Veins

One dyke belonging to this north-northeast-trending suite (divided into two *en echelon* parts), was mapped in the north-central part of the St Lewis River map region. It is a continuation of a dyke mapped south of the Alexis River (north of the present map area) by Gower *et al.* (1987), and which continues from Alexis River northeast for over 50 km. The dyke is exposed along St Lewis River, where it is about 10 m wide, and crops out in isolated exposures a few kilometres north of the river. There is little evidence from aeromagnetic or topographic lineaments that the dyke continues much farther to the southwest. The dyke is a brown-weathering, massive, coarse grained gabbro consisting of euhedral sericitized plagioclase, anhedral later-crystallizing clinopyroxene, opaque minerals and late-crystallizing interstitial material, which includes K-feldspar.

Three, large, parallel quartz veins (up to 400 m wide and, discontinuously, up to 20 km long) transecting the St Lewis River map region are assumed to be coeval with the north-northeast-trending mafic dykes, because of their same trend. These were first recorded by Piloski (1955) and subsequently mapped by Eade (1962). More recently they have been examined by Meyer and Dean (1986) for their silica potential. Meyer and Dean, who only located two of the three dykes (perhaps because one was plotted slightly inaccurately by Eade, 1962), describe them as consisting of quartz and feldspar with minor hematite, magnetite and epidote and showing evidence of multiple intrusion and brecciation.

Younger Phanerozoic Dykes

Dykes postdating the north-northeast-trending dykes are uncommon in the St Lewis River map region. Three outcrops (at the south end of Battle Island, on Hare Island, and on the adjacent mainland to the southwest) are aligned on an 060° trend, which compares closely with dyke trends measured at the three individual localities. We interpret them to be all part of a single intrusion. The dykes are dark grey or brown weathering, fine grained and have widths between 0.2 and 2.0 m. They are vertical, rectiplanar, unmetamorphosed and have well-defined chilled margins (Plate 10). They also show bifurcation, offshoots and sharp changes in trend. The latter feature, in particular, suggests high-level emplacement along pre-existing brittle fractures. The mineralogy is plagioclase, clinopyroxene and opaque minerals, occurring both as small phenocrysts and as quenched groundmass grains. The trend, unmetamorphosed state and high-level features of these dykes suggest correlation with similar dykes farther north (Gower *et al.* 1982, 1987).

Several unmetamorphosed, rectiplanar, parallel dykes between 1- and 5-m wide intrude basement gneiss on Double Island, southeast of Battle Island. These trend at 175° and at least one of the dykes has a very shallow easterly dip. It is unknown whether these dykes are coeval with the east-northeast-trending dykes, or are part of a separate suite (perhaps related to the Tertiary opening of the Labrador Sea).

Plate 10. *Younger Phanerozoic diabase dykes, Hare Island; notebook is 19 cm long.*

STRUCTURE

The structure of the northern half of the map region is dominated by west-northwest trends that are very consistent in the Gilbert River shear belt and in much of the Southwest Pond domain. The northern half of the Pinware terrane shows similar trends but farther south there are more variable directions.

In the Gilbert River shear belt, west-northwest-trending fabrics are imposed on all units, except post-Grenvillian mafic dykes. Planar fabrics are steep to vertical, and lineations plunge shallowly to the west-northwest. Tight to isoclinal westward-plunging folds were observed in several places. Evidence abounds for right-lateral tectonic transposition, especially in the form of rotated K-feldspar megacrysts in granitoid rocks (Plate 11), and shear bands and minor folds in gneisses. Simplification in Figure 2 disguises the fact that many units are sliced-up, tectonic slivers of limited lateral extent.

A major mylonite zone in the vicinity of Fox Harbour marks the boundary between the Gilbert River shear belt and the Southwest Pond domain. This zone consists of steeply northward-dipping, fine grained, finely laminated, dark-weathering, mylonite grading into rocks recognizably derived from monzonite, K-feldspar-megacrystic granodiorite, granite, quartz diorite and amphibolite. Lineations consistently plunge north to northwest at 40 to 65°.

Plate 11. *K-feldspar megacryst showing dextral rotation; Gilbert River shear belt at Mecklenburg Harbour.*

The interior of the Southwest Pond domain lacks well-developed fabrics, most deformation being confined to shear zones that transect the domain and also mark its boundaries. Within the Southwest Pond domain, planar fabrics are steep and trend northwest, except near the zone of northwest-dipping thrusts where foliations have variable trends with an overall regional southwest strike. Lineations have shallow to moderate, west to north plunges.

The shear zones defining the southern boundary of the Southwest Pond domain are marked by well-banded gneiss and mylonite. Mylonite is particularly well developed in the thrust zone and is a very strongly foliated, fine grained flaggy rock having obvious northwest-plunging lineations. A fanning pattern in the lineations is apparent, suggesting noncylindrical folding.

In the Pinware terrane, foliations are well-defined in Group I granitoid rocks and mostly have steep attitudes, although some shallow-plunging or horizonal foliations are present. Lineations are weakly developed or are absent. In some coastal localities it is clear that planar fabrics are the product of several deformational episodes. It seems likely that foliations in Group II granitoid rocks reflect emplacement mechanisms, as they tend to be parallel to pluton boundaries and enclaves within plutons, especially in the eastern lobe. Foliations in Group III granitoid rocks are only present in the outer parts of plutons. The Chateau Pond granite has imposed well-defined fabrics on its country-rock envelope, suggesting intermediate-level, forceful emplacement.

The main post-Grenvillian structures in the map region are north-northeast-trending fractures and faults. Some are defined by fault breccias, which, in places, are veined by quartz, carbonate or (at one locality) pegmatite. The direction and amount of displacement, if any, on most of these fractures is unknown. Late-stage faults and fractures are also expressed by airphoto lineaments discordant to regional structural trends. Dominant trends are northeast and northwest.

METAMORPHISM

Metamorphic assemblages attained upper amphibolite to granulite facies in the Gilbert River shear belt and the Southwest Pond domain and amphibolite facies in the Pinware terrane. Metasedimentary gneiss in both the Gilbert River shear belt and the Southwest Pond domain is characterized by sillimanite–K-feldspar-bearing assemblages. In the Gilbert River shear belt these have been retrogressed to give widespread muscovite. Mafic rocks in both the Gilbert River shear belt and the Southwest Pond domain have garnet and/or amphibole coronitic textures and widespread granoblastic pyroxene and plagioclase. Further evidence of widespread retrogression in the Gilbert River shear belt is the common occurrence of retrograde rims mantling garnet and the presence of prehnite in veinlets in anorthosite.

The presence of sillimanite–K-feldspar-bearing assemblages in the metasedimentary gneisses in the Pinware terrane attests to an early high-grade metamorphism, presumably related to the emplacement of Group I granitoid rocks during the ca. 1650 Ma Labradorian Orogeny. Most rocks, however, do not show evidence of severe metamorphism. Garnet is lacking throughout the terrane, except sporadically near its northern boundary and in a few amphibolites and muscovite schists. Titanite, unstable in quartzofeldspathic rocks at high grades, is common in all granitoid rocks, and quartz–muscovite-bearing assemblages are stable in schists in coastal areas.

One feature of the Pinware terrane is the widespread development of secondary magnetite. This has formed from the oxidation of biotite according to the reaction,

$$\text{biotite} + O_2 = \text{K-feldspar} + \text{magnetite} + H_2O$$

The reaction is demonstrated in many granitoid rocks by the presence of biotite-depleted halos around magnetite grains (Plate 12), where the width of the halo is proportional to the size of the magnetite grain at its centre. The halos do not appear to be especially enriched in K-feldspar, as one might anticipate from the above reaction. We attribute this to dispersal of the K-feldspar-forming components in a fluid phase. Many examples were seen where there is a grain-size increase in quartz and feldspar around individual magnetite grains, or clusters of magnetite grains, which we explain by assuming the presence of a fluid phase. Various stages of this process were observed, the end result is pegmatite produced by coalescing several fluid-enriched patches along pre-existing fractures.

Post-Grenvillian metamorphic effects are slight in the Pinware terrane. The Chateau Pond granite experienced

Plate 12. *Secondary magnetite surrounded by biotite-depleted halo; Cape Charles area.*

sericitization and chloritization. The north-northeast-trending mafic dykes and Lighthouse Cove Formation show moderate low-grade alteration, but metamorphic effects are very weak in the younger Phanerozoic mafic dykes.

ECONOMIC POTENTIAL

The economic potential of the region remains largely untested. Some prospecting and excavation has been carried out on pegmatites in the Seal Islands and Cape Charles areas, and the interior of the region received cursory examination by BRINCO in the early 1950's (Piloski, 1955). More recently, the silica potential of the large north-northeast-trending quartz veins has been assessed by Meyer and Dean (1986). They concluded that only the vein south of Big Pond has a wide enough zone of pure quartz to be considered a good silica prospect.

The targets of potential economic interest outlined by Gower *et al.* (1987) for the Port Hope Simpson map region also apply to the present study area. These include pyritic gossans in metasedimentary gneiss, muscovite in pegmatite, and base metal and platinum-group metal potential in mafic plutonic rocks. Metasedimentary gneiss, however, is not extensive in the St Lewis River map region and pyritic horizons are less common than farther north. None were considered worth assaying for base or precious metals. Pegmatites are abundant in the Pinware terrane and some contain large books of muscovite. The largest observed books (15 cm in diameter) occur at the abandoned prospect at Seal Islands. The muscovite-bearing pegmatites are also characterized by large green alkali feldspar (cf. amazonite) up to 50 cm across. These feldspars were observed at several localities along the coast in the Pinware terrane, and invariably were the last pegmatites to be emplaced.

Other pointers of potential economic interest include the following: 1) malachite staining associated with the Lighthouse Cove Formation, 2) malachite staining in the Alexis River anorthosite—seen where it intersects the coast, 3) blue corundum (cf. sapphire) for its gemstone potential associated with metasedimentary gneiss and anorthosite in the Gilbert River shear belt (Plate 1), 4) granitophile-element mineralization related to Group II and Group III plutons as these rocks show some correlation with incompatible element lake-sediment anomalies, and 5) the extensive pegmatites in the Battle Island area, which intrude chemically reactive metasedimentary gneiss containing traces of fluorite. No anomalous radioactivity was found anywhere in the map region.

ACKNOWLEDGMENTS

Thanks are due to Campbell Churchill, Joan Dicks, Glenda Stratton and Gale Wiseman for their capable assistance. We also thank the residents of Port Hope Simpson, especially Reg Russell, for their hospitality and help. Sealand Helicopters, through their pilots Larry Labadio and Ted Hay provided excellent support. Ken O'Quinn and Wayne Tuttle maintained efficient expediting services from Goose Bay. The manuscript was reviewed and improved by Andy Kerr and Ges Nunn.

REFERENCES

Bostock, H.H., Cumming L.M., Williams, H. and Smyth, W.R.
1983: Geology of the Strait of Belle Isle area, northwestern insular Newfoundland, southern Labrador, and adjacent Quebec. Geological Survey of Canada, Memoir 400, 145 pages.

Christie, A.M.
1951: Geology of the southern coast of Labrador from Forteau to Cape Porcupine, Newfoundland. Geological Survey of Canada, Paper 51-13, 19 pages.

Daly, R.A.
1902: The geology of the northeast coast of Labrador. Bulletin for the Museum of Comparative Zoology, Harvard, Volume 28. Geological Series, Volume 5, pages 205-269.

Douglas, G.V.
1953: Notes on localities visited on the Labrador coast in 1946 and 1947. Geological Survey of Canada, Paper 53-1, 67 pages.

Eade, K.E.
1962: Geology, Battle Harbour—Cartwright, Labrador. Geological Survey of Canada, Map 22-1962.

Erdmer, P.
1986: Geology of the Long Range Inlier in Sandy Lake map area, western Newfoundland. *In* Current Research, Geological Survey of Canada, Paper 86-1B, pages 19-27.

Geological Survey of Canada
1974a: Aeromagnetic maps 13A/1, 13A/2, 13A/7, 13A/8, 3D/4, 3D/5, Newfoundland. Scale 1:63,630. Geological Survey of Canada. Maps 5930G, 5929G, 5935G, 5934G, 5931G, 5933G respectively.

1974b: Aeromagnetic map 13A and 3D, Battle Harbour, Newfoundland. Scale 1:250,000. Geological Survey of Canada, Map 7377G.

1984: Regional lake sediment and water geochemical reconnaissance data, southeast Labrador, NTS 3D, 13A, and parts of 2M and 12P. Geological Survey of Canada Open File 1102; Newfoundland Department of Mines and Energy Open File Labrador 689.

Gower, C.F., Owen, V. and Finn, G.
1982: The geology of the Cartwright Region, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-1, pages 122-130.

Gower, C.F. and Loveridge, W.D.
1987: Grenvillian plutonism in the eastern Grenville province. *In* Radiogenic Age and Isotopic Studies: Report 1, Geological Survey of Canada, Paper 87-2, pages 55-58.

Gower, C.F., Neuland, S., Newman, M. and Smyth, J.
1987: Geology of the Port Hope Simpson map region, Grenville Province, eastern Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 183-199.

Kranck, E.H.
1939: Bedrock geology of the seaboard region of Newfoundland. Newfoundland Geological Survey, Bulletin 19, 44 pages.

Lieber, O.M.
1860: Notes on the geology of the coast of Labrador. Report of the United States Coast Survey for 1860, pages 402-408.

Meyer, J.R. and Dean, P.L.
1986: Industrial minerals in Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 1-8.

Owen, J.V., Campbell, J.E.M. and Dennis, F.A.R.
1987: Geology of the Lake Michel area, Long Range Inlier, western Newfoundland. *In* Current Research, Geological Survey of Canada, Paper 87-1A, pages 643-652.

Packard, A.S.
1891: The Labrador Coast. Hodges N.D.C., New York, 513 pages.

Piloski, M.J.
1955: Geological report on area 'E' Labrador concession. BRINCO Ltd. Unpublished report, 29 pages [Lab 186]

Strong, D.F. and Williams, H.
1972: Early Palaeozoic flood basalts of northwestern Newfoundland, their petrology and tectonic significance. Geological Association of Canada, Volume 24, pages 43-54.

Williams, H. and Stevens, R.K.
1969: Geology of Belle Isle—northern extremity of the deformed Appalachian miogeosynclinal belt. Canadian Journal of Earth Sciences, Volume 6, pages 1145-1157.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 75-83

BIOSTRATIGRAPHIC STUDIES OF ORDOVICIAN CARBONATE ROCKS IN WESTERN NEWFOUNDLAND, 1987

W.D. Boyce, J.S. Ash[1] and I. Knight
Newfoundland Mapping Section

ABSTRACT

Early Ordovician trilobite faunas, poorly known prior to this work, are documented from the Boat Harbour and Catoche formations (St. George Group) of the Pistolet Bay area. These faunas are correlative with the Ross (1951)–Hintze (1953) trilobite zones G_2 to I and are indicative of the Late Jeffersonian Stage and the Cassinian Stage of the Canadian Series.

Previously unreported Early Ordovician trilobites were discovered in the St. George Group of Hare Bay. These new faunas correlate with Ross–Hintze Zones C, E, F, G_2 and H and are indicative of the Late Gasconadian, Demingian, Late Jeffersonian and Cassinian stages of the Canadian Series.

The widespread western Newfoundland trilobite Bathyurus perplexus *Billings, 1865 occurs in a distinctive horizon within the Aguathuna Formation at Big Spring Inlet, Hare Bay. Previous reports of* Acidiphorus *sp. cf.* A. pseudobathyurus *Ross, 1967 from there are incorrect.*

INTRODUCTION

The Ordovician carbonate deposits of the Great Northern Peninsula are the target of regional taxonomic-biostratigraphic studies aimed at correlating their trilobite faunas with those of the standard Ross (1951)–Hintze (1953) trilobite zonations of Utah and Nevada. This report discusses new trilobite material obtained from Schooner Island and Burnt Island in Pistolet Bay and the Brent Islands in Hare Bay (Figure 1). The fossil material was obtained from the Watts Bight, Boat Harbour, Catoche and Aguathuna formations (St. George Group) of Knight and James (1987).

Detailed biostratigraphic sampling of the St. George Group on Schooner Island and Burnt Island was completed in 1987. The sampling results augment and update the work of Boyce (1983b, 1985, 1986). Addition of the previously obtained biostratigraphic information from sections at Boat Harbour and Cape Norman will finally allow the succession of St. George Group trilobite faunas in the Pistolet Bay area to be established.

Reconnaissance biostratigraphic sampling of the St. George Group in Hare Bay was started in 1987.

DETAILED BIOSTRATIGRAPHIC WORK

Schooner Island, Pistolet Bay

Johnson (1949, pages 44 and 45) reported the following trilobite species from St. George Group strata exposed on the northwest shore of Schooner Island:

Bathyurellus fraternus Billings, 1865–probably *Uromystrum affine* (Poulsen, 1937)
Bolbocephalus sp.–probably *Bolbocephalus convexus* (Billings, 1865) or *B. kindlei* Boyce, *in press*
Gignopeltis gibberulus (Billings, 1865)–probably *Benthamaspis gibberula* (Billings, 1865)
Jeffersonia timon (Billings, 1865)
Illaenus fraternus? Billings, 1865–probably *Illaenus* sp. nov.
Petigurus nero (Billings, 1865)

Biostratigraphic sampling of the St. George Group was completed on Schooner Island in 1987. Seventeen new macrofossil collections were made, augmenting the twelve collections made in 1985.

A total of twenty-nine fossiliferous levels have been sampled on Schooner Island for trilobites and conodonts. The collections were obtained from the Barbace Cove Member of the Boat Harbour Formation and the lower three members of the Catoche Formation, which are exposed in sections on the eastern side of the island.

The Barbace Cove Member of the Boat Harbour Formation yielded the following trilobite species:

Bolbocephalus convexus (Billings, 1865)
Bolbocephalus stevensi Boyce, *in press*
Isoteloides peri Fortey, 1979
Jeffersonia angustimarginata Boyce, in press
Peltabellia knighti Boyce, *in press*

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

[1] Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland, A1B 2H2

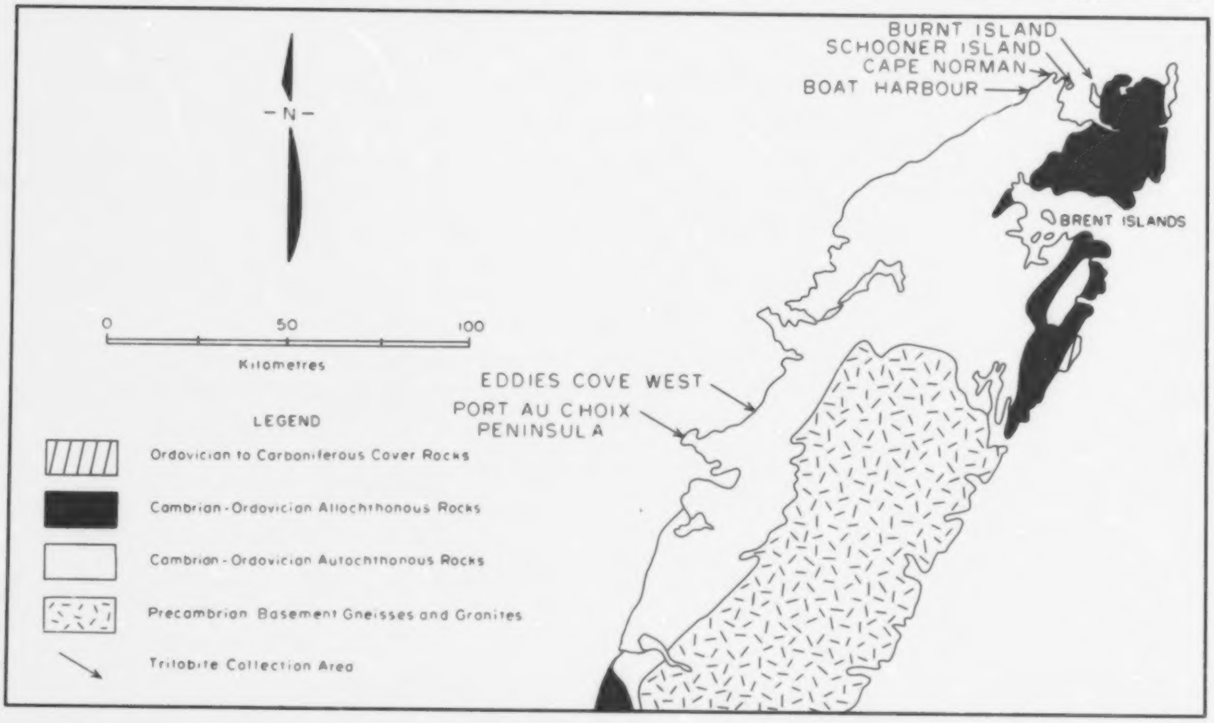

BURNT ISLAND
SCHOONER ISLAND
CAPE NORMAN
BOAT HARBOUR
BRENT ISLANDS
N
0
50
100
Kilometres
EDDIES COVE WEST
PORT AU CHOIX PENINSULA
LEGEND
Ordovician to Carboniferous Cover Rocks
Cambrian-Ordovician Allochthonous Rocks
Cambrian-Ordovician Autochthonous Rocks
Precambrian Basement Gneisses and Granites
Trilobite Collection Area

Figure 1. *Geological elements of the Great Northern Peninsula and trilobite collection areas discussed in this report.*

Strigigenalis brevicaudata Boyce, *in press*
Strigigenalis caudata (Billings, 1865)

The fauna correlates with that of the *Strigigenalis brevicaudata* Zone of the Boat Harbour–Cape Norman area (Figure 2). It is also correlative with Ross–Hintze Zone G_2 and the upper part of the Jeffersonian Stage of the Canadian Series (Figures 3 and 4).

LEGEND (Figure 2)

CARBONATE ROCK TYPES

- ▨ *Dolostone*
- ▨ *Dolostone, limy*
- ☐ *Limestone*
- ☐ *Limestone, dolomitic*

PRIMARY DEPOSITIONAL TEXTURES

- M *Mudstone*
- W *Wackestone*
- P *Packstone*
- G *Grainstone*
- B *Boundstone*

DIAGENETICALLY ALTERED TEXTURES

- x *Crystalline*
- ▭ *Sucrosic*

PARTICLES

- ⊙ *Ooids*
- ● *Intraclasts*
- ◆ *Tabular pebbles (conglomerates)*
- ▲ *Chert*

NOTE: Major rock types indicated on left side of column; minor/associated rock types indicated on right side.

BIOTURBATION
(including burrows, trails, etc.)

- ʃ *Sparsely bioturbated*
- ʃʃ *Moderately bioturbated*
- ʃʃʃ *Extensively bioturbated*

ORGANIC BUILDUPS

- ⌒ *Algal mounds*
- (S) *Stromatolite mounds*
- (T) *Thrombolite mounds*

FOSSIL COLLECTIONS

- - *Single sampled horizon*
- ▮ *Sampled interval*

SEDIMENTARY STRUCTURES

- ▲ *Interference ripples*
- ∿ *Symmetric ripples*
- ⌄⌄ *Mud cracks*

EPIGENETIC STRUCTURES

- ◈ *Pseudobreccia*

DISCONFORMITY

- ∿∿ *Base of pebble bed*

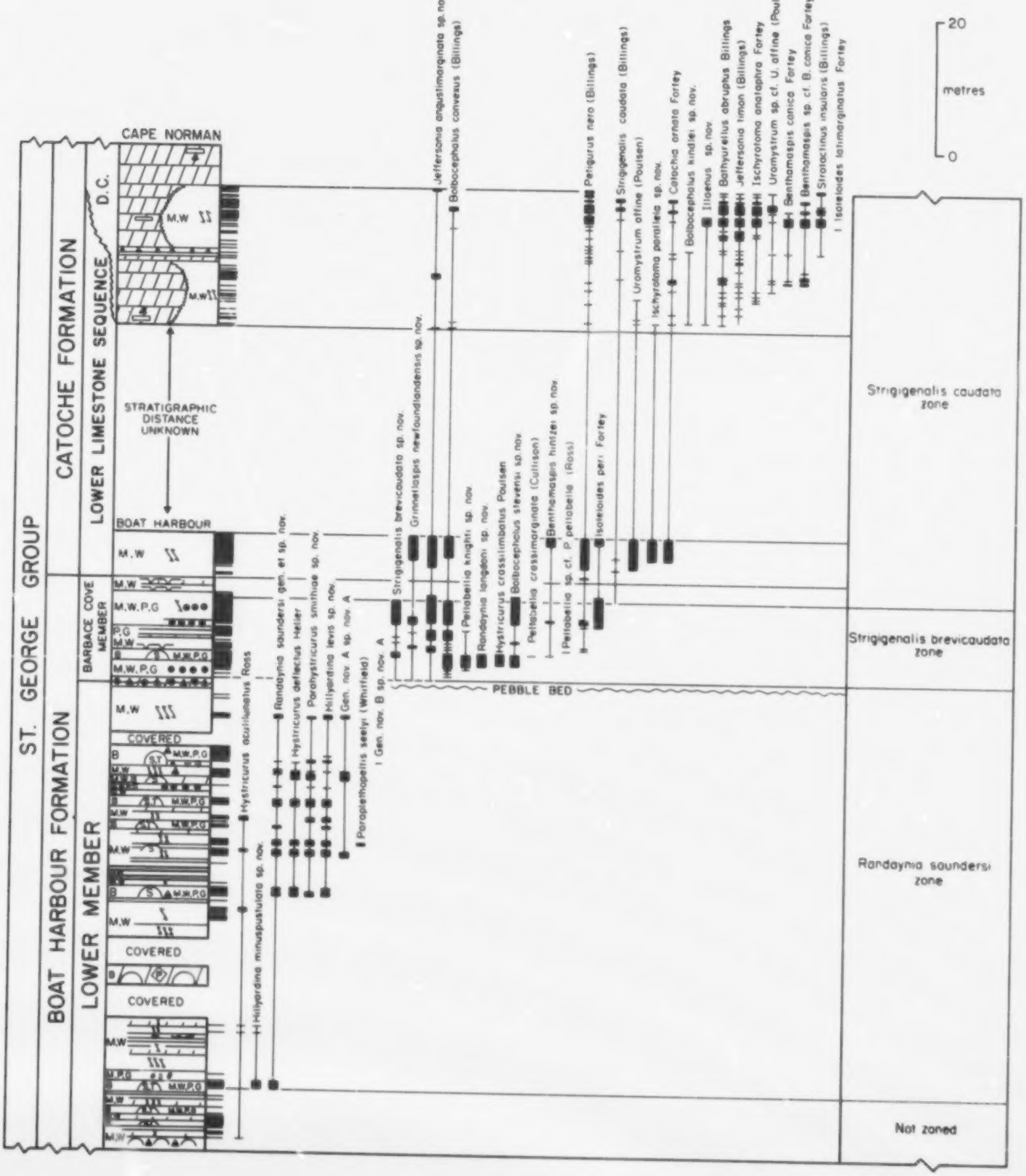


Figure 2. *Biostratigraphic zonation of the Boat Harbour and Catoche formations (St. George Group) in the Boat Harbour–Cape Norman area (Boyce, in press).*

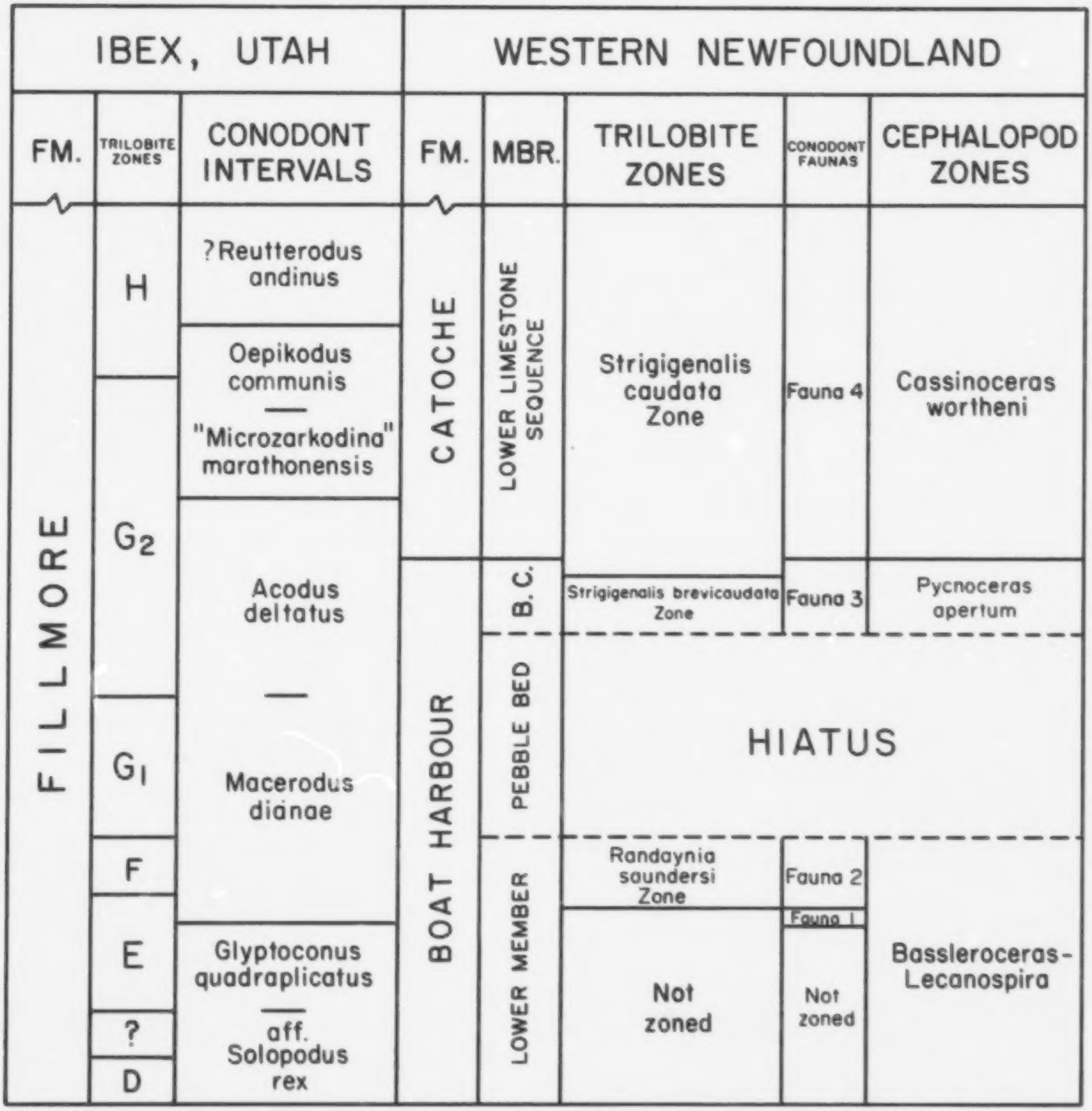

IBEX, UTAH
WESTERN NEWFOUNDLAND
FM.
TRILOBITE ZONES
CONODONT INTERVALS
FM.
MBR.
TRILOBITE ZONES
CONODONT FAUNAS
CEPHALOPOD ZONES
FILLMORE
H
G2
G1
F
E
?
D
?Reutterodus andinus
Oepikodus communis
"Microzarkodina" marathonensis
Acodus deltatus
Macerodus dianae
Glyptoconus quadraplicatus
aff. Solopodus rex
CATOCHE
BOAT HARBOUR
LOWER LIMESTONE SEQUENCE
B. C.
PEBBLE BED
LOWER MEMBER
Strigigenalis caudata Zone
Strigigenalis brevicaudata Zone
Randaynia saundersi Zone
Not zoned
Fauna 4
Fauna 3
Fauna 2
Fauna 1
Not zoned
Cassinoceras wortheni
Pycnoceras apertum
Bassleroceras-Lecanospira
HIATUS

Figure 3. *Correlation of western Newfoundland trilobite zones, conodont faunas and cephalopod zones with the standard trilobite zones and conodont intervals of Ibex, Utah (Boyce,* in press).

The lower bioturbated member (Knight, 1986) of the Catoche Formation yielded the following trilobites:

Bathyurellus abruptus Billings, 1865
Benthamaspis hintzei Boyce, *in press*
Bolbocephalus convexus (Billings, 1865)
Isoteloides peri Fortey, 1979
Jeffersonia angustimarginata Boyce, *in press*
Petigurus nero (Billings, 1865)
Punka sp. nov.
Uromystrum affine (Poulsen, 1937)

The above fauna correlates with that of the *Strigigenalis caudata* Zone of the Boat Harbour–Cape Norman area (Figure 2). It is also correlative with Ross–Hintze Zones G_2 to H and the lower part of the Cassinian Stage of the Canadian Series (Figures 3 and 4).

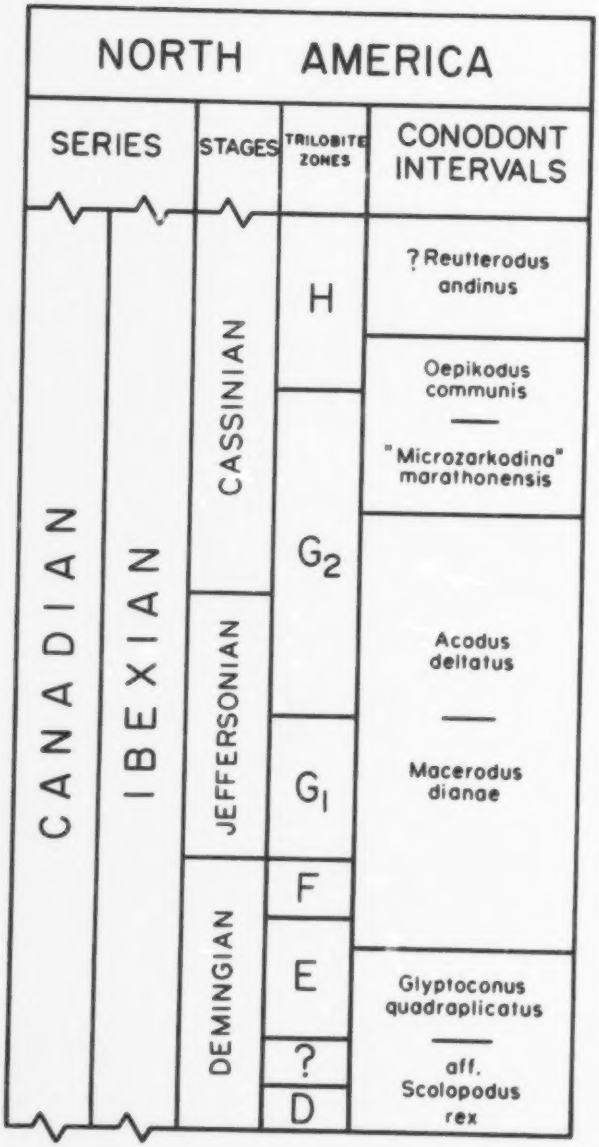


Figure 4. *Correlation of stages of the Canadian Series and trilobite zones and conodont intervals of Ibex, Utah (Boyce, in press).*

The middle mound member (Knight, 1986) of the Catoche Formation yielded the following:

• *Bathyurellus abruptus* Billings, 1865
Bolbocephalus convexus (Billings, 1865)
Illaenus sp. nov.
Jeffersonia sp. undet.
Jeffersonia timon (Billings, 1865)
Petigurus nero (Billings, 1865)
Uromystrum affine (Poulsen, 1937)

The above fauna correlates with that of the *Strigigenalis caudata* Zone of the Boat Harbour–Cape Norman area (Figure 2). It is also correlative with Ross–Hintze Zones G_2 to H and the lower part of the Cassinian Stage of the Canadian Series (Figures 3 and 4).

The upper bioturbated member (Knight, 1986) of the Catoche Formation yielded the following trilobites:

Bathyurellus platypus Fortey, 1979
Illaenus sp. nov.
Ischyrotoma anataphra Fortey, 1979
Jeffersonia timon (Billings, 1865)
Petigurus nero (Billings, 1865)

The above fauna correlates with that of the *Strigigenalis caudata* Zone of the Boat Harbour–Cape Norman (Figure 2) and Eddies Cove West–Port au Choix (Boyce, 1986, Figure 2) areas. It is also correlative with Ross–Hintze Zones G_2 to H and the lower part of the Cassinian Stage of the Canadian Series (Figures 3 and 4).

Burnt Island, Pistolet Bay

On Burnt Island, detailed biostratigraphic sampling of the upper bioturbated and white limestone members (Knight, 1986) of the Catoche Formation was completed. Two sections were investigated. One was on the plateau on the west side of Burnt Island; the other was along the northwest shore.

Twenty-eight new macrofossil horizons were sampled in 1987 on Burnt Island, augmenting the eighteen collections made in 1985. The latter horizons were also resampled.

Altogether, forty-six collections have been made on Burnt Island for trilobites and conodonts. Of these, thirty were obtained from the plateau section. The remaining sixteen were obtained from the shoreline section. The plateau section was more intensely studied than the shoreline section because it was apparently the more fossiliferous of the two. Furthermore, Kindle (1945) and Johnson (1949) obtained their specimens from the plateau section. Figure 5 shows the composite lithostratigraphic and biostratigraphic section constructed from the plateau and shoreline sequences.

Johnson (1949, page 45) reported the following trilobite species from white limestone beds of the St. George Group exposed on the west side of Burnt Island:

Bathyurellus fraternus Billings, 1865–probably *Uromystrum affine* (Poulsen, 1937)
Bathyurus glandicephalus Whitfield, 1890
Bolbocephalus sp. 1–probably *Bolbocephalus convexus (Billings, 1865)*
Bolbocephalus sp. 2–probably *Bolbocephalus kindlei* Boyce, *in press*
Gignopeltis rara (Billings, 1865)
Illaenus fraternus? Billings, 1865–probably *Illaenus* sp. nov.

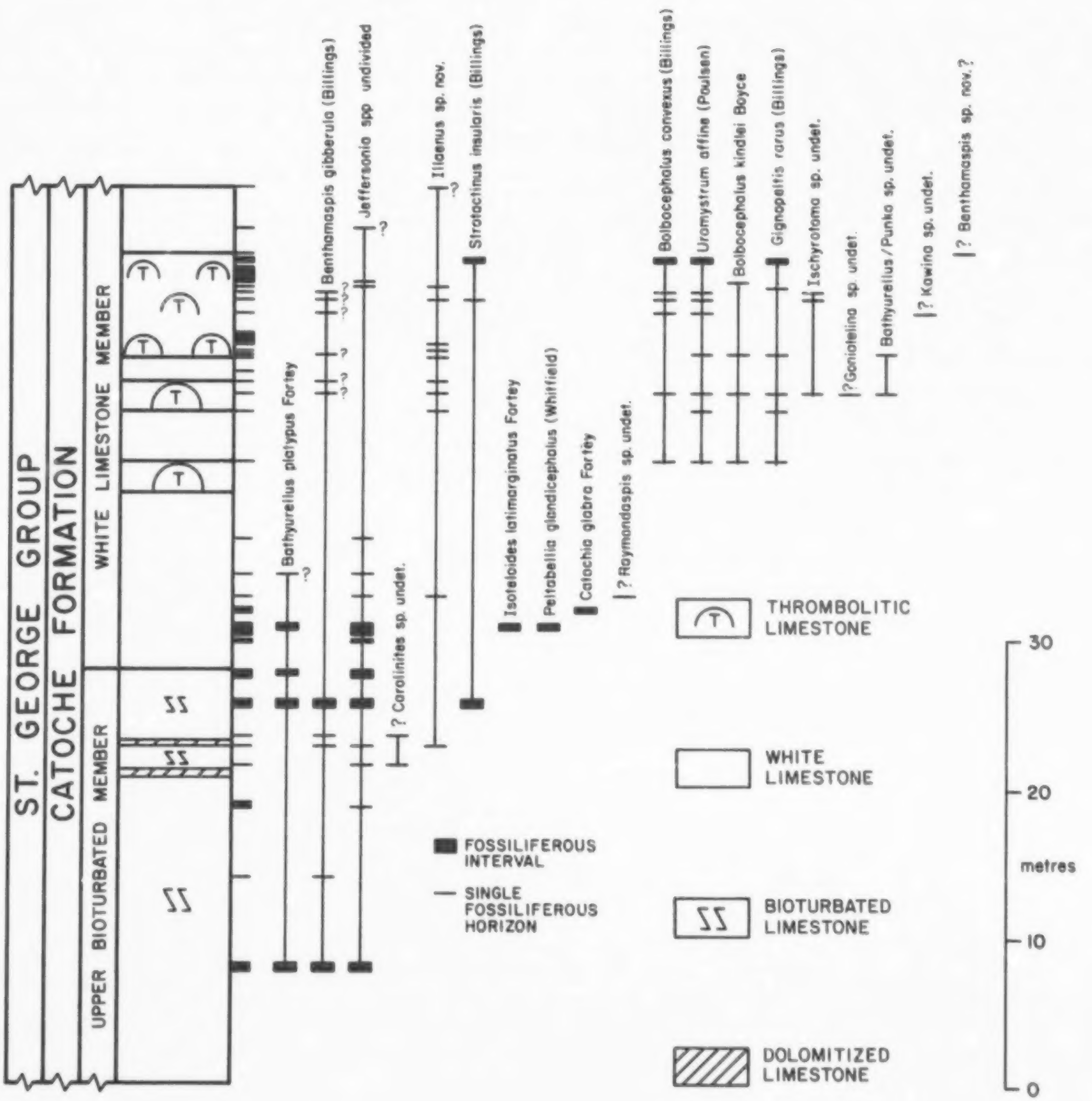

ST. GEORGE GROUP
CATOCHE FORMATION
WHITE LIMESTONE MEMBER
UPPER BIOTURBATED MEMBER
T
Bathyurellus platypus Fortey
Benthamaspis gibberula (Billings)
Jeffersonia spp undivided
? Carolinites sp. undet.
Illaenus sp. nov.
Strotactinus insularis (Billings)
Isoteloides latimarginatus Fortey
Peltabellia glandicephalus (Whitfield)
Catochia glabra Fortey
? Raymondaspis sp. undet.
Bolbocephalus convexus (Billings)
Uromystrum affine (Poulsen)
Bolbocephalus kindlei Boyce
Gignopeltis rarus (Billings)
Ischyrotoma sp. undet.
?Goniotelina sp. undet.
Bathyurellus/Punka sp. undet.
? Kawina sp. undet.
? Benthamaspis sp. nov.?
?
FOSSILIFEROUS INTERVAL
SINGLE FOSSILIFEROUS HORIZON
THROMBOLITIC LIMESTONE
WHITE LIMESTONE
BIOTURBATED LIMESTONE
DOLOMITIZED LIMESTONE
30
20
metres
10
0

Figure 5. *Composite lithostratigraphic and biostratigraphic section through the upper bioturbated and white limestone members of the Catoche Formation, western side of Burnt Island, Pistolet Bay.*

Jeffersonia timon (Billings, 1865)
Niobe? sp.—possibly *Isoteloides latimarginiatus* Fortey, 1979
Onchonotus globosus (Billings, 1860)—possibly *Ischyrotoma anataphra* Fortey, 1979

The upper bioturbated member of the Catoche Formation yielded the following trilobites:

Bathyurellus platypus Fortey, 1979
Benthamaspis gibberula (Billings, 1865)
Bolbocephalus kindlei Boyce, *in press*
?Carolinites sp. undet.
Illaenus sp. nov.
Isoteloides latimarginatus Fortey, 1979
Jeffersonia angustimarginata Boyce, *in press*
Jeffersonia timon (Billings, 1865)
Petigurus nero (Billings, 1865)
Strotactinus insularis (Billings, 1865)

The above fauna correlates with that of the *Strigigenalis caudata* Zone of the Boat Harbour–Cape Norman (Figure 2) and Eddies Cove West–Port au Choix (Boyce, 1986, Figure 2) areas. It is also correlative with Ross–Hintze Zones G_2 to H and the lower part of the Cassinian Stage of the Canadian Series (Figures 3 and 4).

The white limestone member of the Catoche Formation yielded the following trilobites:

Bathyurellus platypus Fortey, 1979
Benthamaspis gibberula (Billings, 1865)
?Benthamaspis sp. undet.
Bolbocephalus convexus (Billings, 1865)
Bolbocephalus kindlei Boyce, *in press*
Gignopeltis rarus (Billings, 1865)
?Goniotelina sp. undet.
Illaenus sp. nov.
Ischyrotoma sp. undet.
Isoteloides latimarginatus Fortey, 1979
Jeffersonia angustimarginata Boyce, *in press*
Jeffersonia timon (Billings, 1865)
?Kawina sp. undet.
Peltabellia glandicephalus (Whitfield, 1890)
?Punka sp. undet.
?Raymondaspis sp. undet.
Strotactinus insularis (Billings, 1865)
Uromystrum sp. nov.
Uromystrum affine (Poulsen, 1937)

The above fauna correlates with that of the *Strigigenalis caudata* Zone of the Eddies Cove West–Port au Choix area (Boyce, 1986, Figure 2). It is also correlative with Ross–Hintze Zones H to I and the upper part of the Cassinian Stage of the Canadian Series (Figures 3 and 4).

Eddies Cove West

Biostratigraphic sampling of the Boat Harbour Formation (St. George Group) for trilobites and conodonts near Eddies Cove West (Figure 1) was completed in 1987. Addition of previously obtained biostratigraphic information (Boyce, 1983a, 1985) from there, and the Port au Choix Peninsula (Fortey, 1979; Boyce 1983a, 1985, 1986; Williams *et al.*, 1987) will finally allow the succession of St. George Group trilobite faunas of that area to be established.

RECONNAISSANCE BIOSTRATIGRAPHIC WORK

Pistolet Bay

On the south shore of Pistolet Bay, three fossiliferous limestone units were sampled in the vicinity of Triangle Point, near the old St. Anthony airport. These units occur in the upper part of the Middle Ordovician Goose Tickle Formation (L. Quinn, personal communication, 1987). Articulate brachiopods, echinoderms (eocrinoid columnals), ostracodes and one trilobite were obtained and remain to be identified.

Hare Bay

Murray (*in* Murray and Howley, 1881) was the first worker to report Ordovician trilobites from Hare Bay. He reported the occurrence of the trilobite *Petigurus nero* (Billings, 1865). Since then, biostratigraphic investigations have been sporadic and little has been published.

Reconnaissance sampling of the Watts Bight, Boat Harbour, Catoche and Aguathuna formations (St. George Group) commenced in 1987 on the southern shore of the Brent Islands in Hare Bay. Twenty-six *previously unsampled* horizons in three sections yielded macrofossils. These were also sampled for conodonts. Another nineteen conodont samples were taken from horizons lacking macrofossils–chiefly in the Watts Bight and Boat Harbour formations.

The top of the Watts Bight Formation on South Brent Island yielded the trilobite *Parahystricurus* sp. cf. *P.* sp. I (Ross, 1951; Plate 17, Figures 1–3). In Utah, *Parahystricurus* sp. I occurs in Ross–Hintze Zone C (Ross, 1951).

Trilobites were recovered for the first time from the lower member of the Boat Harbour Formation on North Brent Island. The following trilobite species were collected:

Hystricurus oculilunatus Ross, 1951
Leiostegium proprium Boyce, *in press*
Parahystricurus smithiae Boyce, *in press*
Paraplethopeltis seelyi (Whitfield, 1889)

The fauna correlates with that of the *Randaynia saundersi* Zone of the Boat Harbour–Cape Norman area (Figure 2). It is also correlative with Ross–Hintze Zones E to F and the Demingian Stage of the Canadian Series (Figures 3 and 4).

The Barbace Cove Member of the Boat Harbour Formation on North Brent Island yielded the following trilobite species:

Bolbocephalus convexus (Billings, 1865)
Bolbocephalus stevensi Boyce, *in press*
Grinnellaspis newfoundlandensis Boyce, *in press*
Isoteloides peri Fortey, 1979
Jeffersonia angustimarginata Boyce, *in press*
Peltabellia knighti Boyce, *in press*
Strigigenalis brevicaudata Boyce, *in press*

The fauna correlates with that of the *Strigigenalis brevicaudata* Zone of the Boat Harbour–Cape Norman area (Figure 2). It is also correlative with Ross–Hintze Zone G_2 and the upper part of the Jeffersonian Stage of the Canadian Series (Figures 3 and 4).

Dr. R.A. Fortey of the British Museum (Natural History) identified the following trilobites from the basal beds of the Catoche Formation on North Brent Island (N.P. James, personal communication, 1979):

Bolbocephalus convexus (Billings, 1865)
Illaenus sp.
Jeffersonia timon (Billings, 1865)
Petigurus nero (Billings, 1865)

Boyce has also identified the following from collections obtained by Dr. R.K. Stevens (Memorial University of Newfoundland) from the Catoche Formation of Hare Bay:

Bathyurellus abruptus Billings, 1865
?Bolbocephalus sp. undet.
Illaenus sp. nov.
Ischyrotoma sp. undet.
Jeffersonia sp. undet.
Jeffersonia timon (Billings, 1865)
Petigurus nero (Billings, 1865)
Punka flabelliformis Fortey, 1979
Strigigenalis sp. undet.
Uromystrum sp. cf. *U. affine* (Poulsen, 1937)

The above fauna correlates with that of the *Strigigenalis caudata* Zone of the Boat Harbour–Cape Norman area (Figure 2). It is also correlative with Ross–Hintze Zones G_2 to H and the lower part of the Cassinian Stage of the Canadian Series (Figures 3 and 4).

The Catoche Formation has also yielded trilobites at other localities in Hare Bay. Beds exposed at the community wharves in Main Brook have yielded *Jeffersonia timon* (Billings, 1865). *Petigurus nero* (Billings, 1865) and *Uromystrum* sp. cf. *U. affine* (Poulsen, 1937) have been collected on the north shore of Pradet Island (Boyce, *in* Stouge, 1981). *Petigurus nero* (Billings, 1865) has also been collected on Maria Island (Boyce, 1983b, *in press*).

The writers visited an important monospecific trilobite horizon in the Aguathuna Formation at Big Spring Inlet (south shore of Hare Bay). From there, Ross and James (1987), Williams *et al.* (1987) and Knight and James (1987) reported *Acidiphorus* sp. cf. *A. pseudobathyurus* Ross, 1967. However the only trilobite found at the locality in 1987 was the widespread western Newfoundland species *Bathyurus perplexus* Billings, 1865. The previous reports of *Acidiphorus* sp. cf. *A. pseudobathyurus* are therefore judged as misidentifications. *Bathyurus perplexus* Billings, 1865 probably indicates a Ross–Hintze Zone L (Early Whiterock) age (Williams *et al.*, 1987).

A sample for conodonts was also taken at the Big Spring Inlet *Bathyurus perplexus* horizon. Knight collected at least ten other samples for conodonts at Big Spring Inlet from the Catoche, Aguathuna and Table Point formations.

SUMMARY

Ordovician trilobite faunas from the Boat Harbour and Catoche formations on Schooner Island and Burnt Island in Pistolet Bay range in age from Ross–Hintze Zone G_2 (Late Jeffersonian) to Zone I (Late Cassinian).

Newly discovered Ordovician trilobite faunas from the Brent Islands in Hare Bay range in age from Ross–Hintze Zone C (Late Gasconadian) to Zone H (Cassinian).

Previous reports of *Acidiphorus* sp. cf. *A. pseudobathyurus* Ross, 1967 from the Aguathuna Formation in Big Spring Inlet, Hare Bay represent misidentifications of *Bathyurus perplexus* Billings, 1865.

ACKNOWLEDGMENTS

J. Botsford, P.A. Cawood, L. Quinn, D.N. Reusch and R.K. Stevens are thanked for enlivening the summer. Mr. and Mrs. Cadman Pelley of Main Brook are thanked for their hospitality. Mr. Rex Boyd deserves thanks for letting us park our trailers on his land for free. Austin Patey of River of Ponds is once again thanked for his assistance. B.H. O'Brien and P.A. O'Neill critically reviewed the manuscript.

REFERENCES

Billings, E.

1860: On some new species of fossils from the limestone near Point Levis opposite Quebec. Canadian Naturalist, Volume 5, pages 301-324.

1865: Palaeozoic fossils. Volume 1. Containing descriptions and figures of new or little known species of organic remains from the Silurian rocks. 1861-1865. Geological Survey of Canada, 426 pages.

Boyce, W.D.

1983a: Preliminary Ordovician trilobite biostratigraphy of the Eddies Cove West–Port au Choix area, western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 11-15.

1983b: Early Ordovician trilobite faunas of the Boat Harbour and Catoche Formations (St. George Group) in the Boat Harbour–Cape Norman area, Great Northern Peninsula, western Newfoundland. Unpublished M.Sc thesis, Memorial University of Newfoundland, St. John's, 272 pages.

1985: Cambrian-Ordovician biostratigraphic investigations, Great Northern Peninsula, western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 60-70.

1986: Ordovician biostratigraphic investigations, Great Northern Peninsula, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 161-168.

In press: Early Ordovician trilobite faunas of the Boat Harbour and Catoche Formations (St. George Group) in the Boat Harbour–Cape Norman area, Great Northern Peninsula, western Newfoundland. Newfoundland Department of Mines, Mineral Development Division.

Fortey, R.A.
1979: Lower Ordovician trilobites from the Catoche Formation (St. George Group), western Newfoundland. Geological Survey of Canada, Bulletin 321, pages 69-114.

Hintze, L.F.
1953: Lower Ordovician trilobites from western Utah and eastern Nevada. Utah Geological and Mineralogical Survey, Bulletin 48, 249 pages.

Johnson, H.
1949: Excerpts from 'Geology of Western Newfoundland'. Unpublished manuscript, Newfoundland Geological Survey, 48 pages. [NFLD (188)]

Kindle, C.H.
1945: Geology of the Pistolet Bay area, summary report. Unpublished manuscript, Newfoundland Geological Survey, 12 pages. [2M (3)]

Knight, I.
1986: Ordovician sedimentary strata of the Pistolet Bay and Hare Bay area, Great Northern Peninsula, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 147-160.

Knight, I. and James, N.P.
1987: The stratigraphy of the Lower Ordovician St. George Group, western Newfoundland: the interaction between eustasy and tectonics. Canadian Journal of Earth Sciences, Volume 24, pages 1927-1951.

Murray, A. and Howley, J.P.
1881: Geological Survey of Newfoundland, 1864-1880. (Reprints of reports, revised and corrected). London, 536 pages.

Poulsen, C.
1937: On the Lower Ordovician faunas of east Greenland. Meddelelser om Gronland, Volume 119, pages 1-72.

Ross, R.J., Jr.
1951: Stratigraphy of the Garden City Formation in northeastern Utah and its trilobite faunas. Yale University, Peabody Museum of Natural History, Bulletin 6, 161 pages.

1967: Some Middle Ordovician brachiopods and trilobites from the Basin Ranges, western United States. United States Geological Survey, Professional Paper 523-D, 43 pages.

Ross, R.J., Jr. and James, N.P.
1987: Brachiopod biostratigraphy of the middle Ordovician Cow Head and Table Head groups, western Newfoundland. Canadian Journal of Earth Sciences, Volume 24, pages 70-95.

Stouge, S.
1981: Cambrian-Middle Ordovician stratigraphy of Salmon River region, southwest Hare Bay, Great Northern Peninsula. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-1, pages 1-16.

Whitfield, R.P.
1889: Observations on some imperfectly known fossils from the Calciferous sandrock of Lake Champlain and descriptions of several new forms. American Museum of Natural History Bulletin, Volume 2, pages 41-63.

1890: Observations on the fauna of the rocks at Fort Cassin, Vermont, with descriptions of a few new species. American Museum of Natural History Bulletin, Volume 3, pages 25-39.

Williams, S.H., Boyce, W.D. and James, N.P.
1987: Graptolites from the Lower-Middle Ordovician St. George and Table Head groups, western Newfoundland, and their correlation with trilobite, graptolite, brachiopod and conodont zones. Canadian Journal of Earth Sciences, Volume 24, pages 456-470.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 85-98

GEOCHEMISTRY AND PETROLOGY OF LOWER PALEOZOIC PLATFORM-EQUIVALENT SHALES, WESTERN NEWFOUNDLAND

J.W. Botsford
Department of Earth Sciences
Memorial University of Newfoundland

ABSTRACT

A total of 274 shale samples have been collected from a variety of lower Paleozoic tectonostratigraphic settings in western Newfoundland. Thick shale units of particular interest occur in the Humber Arm and Hare Bay allochthons, and within the Table Head Group at the top of the autochthonous Cambro-Ordovician platformal sequence. Preliminary results of shale analyses indicate localized, anomalous concentrations (roughly 300 ppm) of Zn, Cu, Pb and Ni. In part of the Humber Arm Allochthon (Cow Head Group) these anomalies occur throughout the Middle Cambrian to Middle Ordovician stratigraphic sequence, and are related to the early precipitation of sulphides associated with organic carbon. In the laterally equivalent Northern Head group (Bay of Islands area) sulphide precipitation is localized in Arenigian rocks at the base of the flysch sequence, and may be related to: 1) early diagenetic mobilization of metals during oxidizing marine conditions or 2) subsequent burial history. Shale of the Middle Ordovician Black Cove Formation contains sphalerite associated with early precipitated pyrite.

INTRODUCTION

The objective of this project is to evaluate the potential of lower Paleozoic shale in western Newfoundland as a source of base-metal mineralization in nearby platform carbonates of similar age, and as hosts of sedimentary exhalative base-metal deposits.

Sixty-one base-metal mineral occurrences within the carbonate platform of western Newfoundland have been documented in a recent study conducted as part of the Canada-Newfoundland Mineral Development Agreement (Saunders and Strong, 1986). These occur throughout the Middle Cambrian to Middle Ordovician carbonate rocks from the Port au Port Peninsula to the tip of the Great Northern Peninsula. Many, including the Daniels Harbour ore body, are hosted by the Lower Ordovician St. George Group.

Shale units of equivalent age are disposed in several tectonostratigraphic settings in western Newfoundland. These shales occur as: 1) interbedded units within the Lower Cambrian to Middle Ordovician carbonate-dominated platformal sequence; 2) a black shale-dominated interval (Black Cove Formation) of Middle Ordovician age, which occurs at the top of the platformal sequence and is thought to be related to margin collapse; and 3) thick shale intervals within Lower Cambrian to Lower Ordovician deep-water equivalents of the platformal sequence, which occur in the Humber Arm and Hare Bay allochthons.

Objectives of this project are:

1) to identify anomalous metal concentrations in shales and document the nature of their occurrence through the use of the SEM/EDAX;
2) to establish if significant trends in major and/or trace element chemistry occur and if they vary with stratigraphic position or tectonic setting;
3) to characterize the depositional and early diagenetic conditions indicated by organic carbon/sulphur relationships;
4) to identify potential temporal changes in oceanic conditions, which may have governed the transportation or precipitation of metals, through the examination of pyritic sulphur isotopic signatures in a representative subset of samples (of known age); this will be augmented with determination of sulphur isotopic signatures of localized sulphate occurrences; and
5) to characterize the burial diagenetic history of individual sedimentary sequences through the determination of illite crystallinity index for a representative subset of samples.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989; project carried by the Geological Survey of Canada, DSS contract 23233-7-0223/01-ST.

TECTONOSTRATIGRAPHIC SETTING OF WESTERN NEWFOUNDLAND SHALES

Regional Setting

The Humber Zone of western Newfoundland (Williams, 1979) records 1) the establishment of a passive continental margin in the late Precambrian/Early Cambrian, 2) continental margin sedimentation spanning the Cambrian to Middle Ordovician, 3) the destruction of the margin during Middle Ordovician Taconic orogenesis and 4) subsequent deformation during Acadian orogenesis.

A mixed siliciclastic–carbonate Lower Cambrian sequence (Labrador Group) overlies rifted Grenvillian basement, and is overlain by a thick (roughly 1500 m) platformal carbonate sequence (Port au Port Group, St. George Group) spanning the Middle Cambrian to Lower Ordovician (Figure 1). Equivalent deep-water strata are preserved in two major allochthons, the Humber Arm Allochthon in the south and the Hare Bay Allochthon in the north (Figure 4). Block-faulting and foundering of the platform is recorded by the deposits of the Middle Ordovician Table Head Group atop the platformal sequence (Klappa *et al.*, 1980; Stenzel and James, 1987). It preceded the structural emplacement of the allochthons onto the platform.

Autochthonous Platformal Sequence

The autochthonous platformal sequence (Figure 1) was dominated by shallow-water sedimentation, and is generally poor in shale.

The Lower to Middle Cambrian Labrador Group (James and Stevens, 1982; Knight and Boyce, 1987) comprises: 1) sandstone of the basal Bradore Formation, overlain by 2) shale, siltstone, minor sandstone and carbonate of the Forteau Formation that is in turn overlain by 3) the Hawke Bay Formation which is dominated by quartzitic sandstone with locally developed shale and limestone units.

The Middle to Upper Cambrian Port au Port Group (Chow and James, 1987) consists of the March Point, Petit Jardin and Berry Head formations, all having shallow-water carbonate lithologies containing minor shale interbeds. The Lower to lower Middle Ordovician St. George Group (Knight and James, 1987) comprises shallow-water carbonates of the Watts Bight, Boat Harbour, Catoche and Aguathuna formations. The Aguathuna Formation straddles the Lower/Middle Ordovician boundary and contains several depositional breaks indicated by stratiform breccias.

Locally, an unconformity separates the St. George Group from the overlying Middle Ordovician Table Head Group (Klappa *et al.*, 1980; Ross and James, 1987). The Table Head Group consists of: 1) peritidal to subtidal carbonates in the lower part (Table Point Formation), followed by 2) local hemipelagic slope sediments deposited in response to differential subsidence (Table Cove Formation), and 3) rapid collapse, resulting in the deposition of mud of the Black Cove Formation across a block-faulted submarine topography.

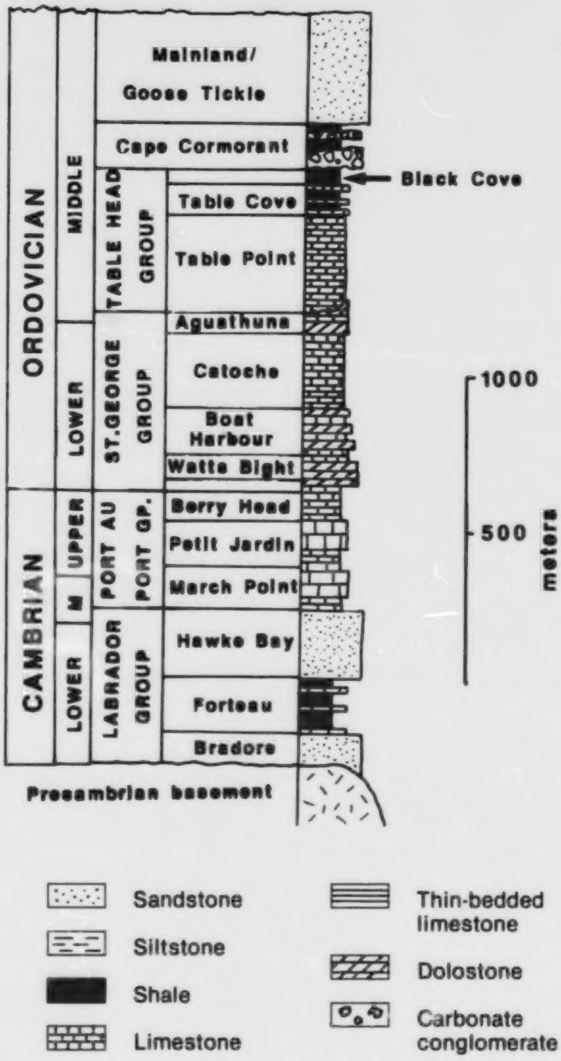

ORDOVICIAN
CAMBRIAN
MIDDLE
LOWER
UPPER
M
TABLE HEAD GROUP
ST. GEORGE GROUP
PORT AU PORT GP.
LABRADOR GROUP
Mainland/ Goose Tickle
Cape Cormorant
Black Cove
Table Cove
Table Point
Aguathuna
Catoche
Boat Harbour
Watts Bight
Berry Head
Petit Jardin
March Point
Hawke Bay
Forteau
Bradore
Precambrian basement
1000
500
meters
Sandstone
Siltstone
Shale
Limestone
Thin-bedded limestone
Dolostone
Carbonate conglomerate

Figure 1. *Schematic summary of Lower Paleozoic autochthonous, platformal sequence, western Newfoundland. St. George Group contains unnamed unit at base.*

This topography was progressively overlain by Middle Ordovician flysch (Mainland sandstone and Goose Tickle Formation) comprising sandstone, siltstone and shale. This was commonly preceded or punctuated by carbonate debris flows (Cape Cormorant Formation) derived from erosion of Table Head and older carbonates (Stenzel and James, 1987).

Allochthonous Deep-Water Sequences

The Humber Arm and Hare Bay allochthons are broadly similar in that they comprise thrust slices of predominantly sedimentary lithologies in the lower part, overlain by volcanic and igneous slices of oceanic affinity, and capped by ophiolite complexes; all are separated by mélange zones of variable thickness. Both allochthons structurally overlie the autochthonous platformal sequence and are bounded by mélange. The internal stratigraphy and structure of the Humber Arm Allochthon is presently better understood than the Hare Bay Allochthon.

Humber Arm Allochthon

The Humber Arm Allochthon is centred on the Bay of Islands and extends from the Port au Port Peninsula to Portland Creek (Figure 4).

A succession of deep-water sedimentary units, equivalent to the platformal sequence described above, is exposed in the lower part of the Humber Arm Allochthon (Figure 2) and is termed the Humber Arm Supergroup (Stevens, 1970). At the base, red and green shale and sandstone of the ?Lower Cambrian Summerside Formation occur. These lithologies pass upward into the Lower to Middle Cambrian Irishtown Formation which contains quartzitic sandstone, conglomerate and shale. These units are the deep-water equivalents of the Labrador Group.

The Irishtown Formation is overlain by Middle Cambrian to Lower Ordovician deep-water carbonate slope deposits, which reflect the style of carbonate sedimentation on the platform (James and Stevens, 1986; Botsford, 1987). In the Bay of Islands area, this sequence is informally termed the Northern Head group (Botsford, 1987), whereas laterally equivalent strata to the north are termed the Cow Head Group (James and Stevens, 1986) (Figure 2). Although both sequences comprise carbonate gravity deposits and shale, differences between them reflect an irregular platform margin morphology that has controlled their deposition and local paleoceanographic conditions (Botsford, 1987) (see below).

Both units are conformably overlain by flysch, termed the Eagle Island formation (Botsford, 1987) in the Bay of Islands area, and the Lower Head formation in the Cow Head area (Williams *et al.*, 1985). These units are regarded as facies equivalents of the autochthonous Mainland sandstone. The Humber Arm Allochthon is structurally thin at its northern and southern extremities, and only the Cow Head Group and Lower Head formation are preserved, in imbricate slices, in the Cow Head area.

Hare Bay Allochthon

The Hare Bay Allochthon is centered on Hare Bay, and extends from Canada Bay, in the south, to the northeast tip of the Great Northern Peninsula (Figure 4).

Six major structural slices have been mapped (Williams and Smyth, 1983), and are generally separated by shaly mélange. Several of these slices contain sedimentary lithologies, including shale units, and are described here.

The Northwest Arm Formation is exposed on the western margin of the allochthon and consists of thinly interbedded black and green shale, minor carbonate conglomerate, sandstone and chert. The formation has yielded Lower Ordovician graptolites (Tuke, 1968). Strong similarities with the upper part of the Northern Head group (Middle Arm Point formation) and an apparently conformable relationship with overlying sandstones of the Goose Tickle Formation have been noted by the writer, and a similar depositional setting is considered likely.

The Maiden Point Formation is contained in the structurally overlying thrust slice. It comprises a thick sequence of unfossiliferous, bedded quartzose sandstone and shale interbeds, plus minor mafic volcanics. The age of the Maiden Point Formation is uncertain, but it is tentatively regarded as Early Cambrian (Williams and Smyth, 1983). The Maiden Point Formation is similar to portions of the Summerside and Irishtown formations of the Humber Arm Allochthon.

The structurally overlying Milan Arm Mélange is similar to other mélange zones in the allochthon, but it appears to occupy a consistent structural position and contains huge rafts of predominantly volcanic blocks. These are surrounded by a black and green shale matrix.

The Cape Onion Formation occurs in an overlying thrust slice and is confined to the northern part of the allochthon. It consists of basaltic pillow lavas and black, pyritic shale that has yielded Lower Ordovician (Tremadoc) graptolites (Erdtmann, 1971; Williams and Smyth, 1983).

Eastern Margin of the Humber Arm Allochthon

In the complex zone immediately east of the Humber Arm Allochthon, several fault-bounded, variably deformed rock units have been identified, but are still of uncertain age and affinity. Both parautochthonous slices of the platformal sequence, possibly representative of a more easterly, shale-rich facies, and equivalents of parts of the Humber Arm Allochthon are thought to occur (Figure 3).

The Reluctant Head Formation comprises thin-bedded limestone and limestone breccia with grey, dolomitic shale (locally phyllite) and is regarded as Cambrian in age (Lilly, 1963; Williams and Cawood, 1986).

The Whale Back formation (Williams and Cawood, 1986) contains green sandstone, siltstone and shale; the formation resembles and is tentatively correlated with the Middle Ordovician Goose Tickle Formation.

The Pinchgut group (Williams and Cawood, 1986) occurs in faulted contact with the Irishtown Formation. It contains thin-bedded limestone, grey-green dolomitic shale and thick-bedded carbonate conglomerate. The age and depositional setting is uncertain. Williams and Cawood (1986) have suggested that the Pinchgut group represents an eastern facies of the platformal carbonate sequence. However, lithologically, the unit resembles the lower part of the Cooks Brook Formation in clast composition of conglomerate, and bedding style of conglomerate and shale (personal observations, 1987). This, and the proximity to the Irishtown Formation, suggests

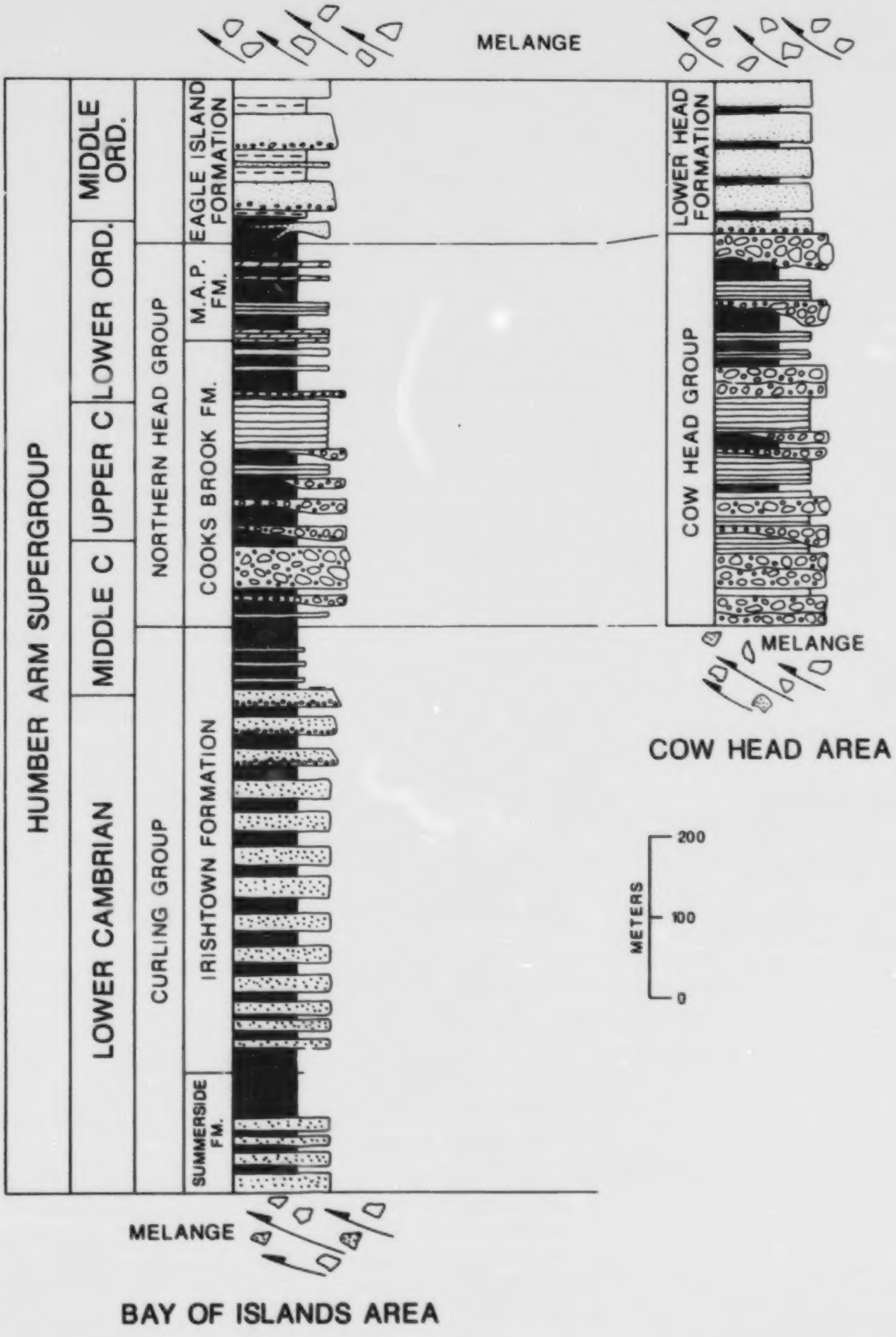

MELANGE
HUMBER ARM SUPERGROUP
MIDDLE ORD.
LOWER ORD.
UPPER C
MIDDLE C
LOWER CAMBRIAN
NORTHERN HEAD GROUP
CURLING GROUP
EAGLE ISLAND FORMATION
M.A.P. FM.
COOKS BROOK FM.
IRISHTOWN FORMATION
SUMMERSIDE FM.
MELANGE
BAY OF ISLANDS AREA
MELANGE
LOWER HEAD FORMATION
COW HEAD GROUP
MELANGE
COW HEAD AREA
METERS
200
100
0

Figure 2. *Schematic summary of the Humber Arm Supergroup, in the Humber Arm Allochthon, illustrating the relationship of the Bay of Islands and Cow Head areas. M.A.P. Fm. is Middle Arm Point formation; see Figure 1 for Legend.*

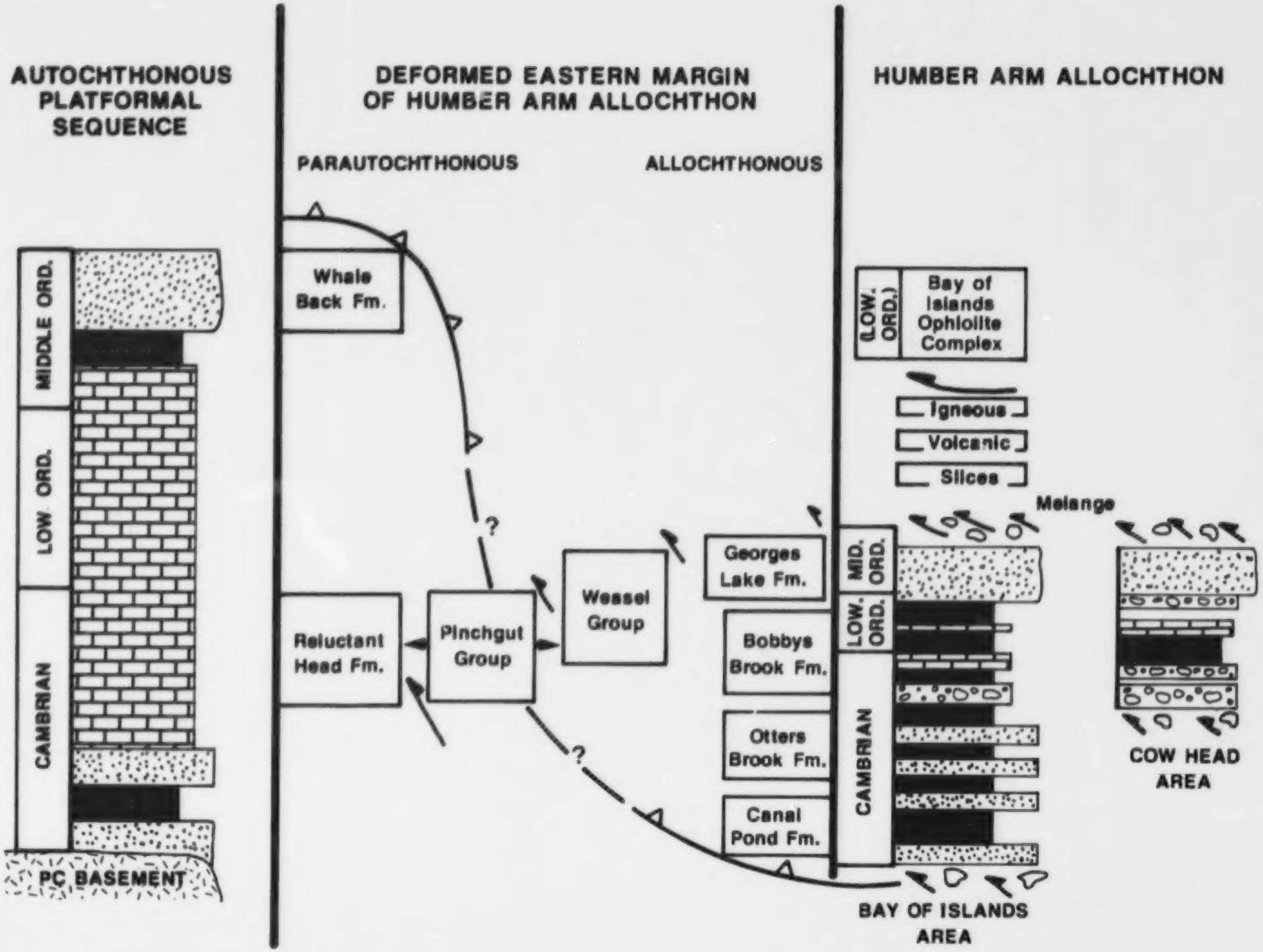

AUTOCHTHONOUS PLATFORMAL SEQUENCE
DEFORMED EASTERN MARGIN OF HUMBER ARM ALLOCHTHON
HUMBER ARM ALLOCHTHON
PARAUTOCHTHONOUS
ALLOCHTHONOUS
MIDDLE ORD.
LOW ORD.
CAMBRIAN
PC BASEMENT
Whale Back Fm.
Reluctant Head Fm.
Pinchgut Group
Wessel Group
?
?
Georges Lake Fm.
Bobbys Brook Fm.
Otters Brook Fm.
Canal Pond Fm.
LOW. ORD.)
Bay of Islands Ophiolite Complex
Igneous
Volcanic
Slices
Melange
MID. ORD.
LOW. ORD.
CAMBRIAN
BAY OF ISLANDS AREA
COW HEAD AREA

Figure 3. *Schematic summary indicating the inferred tectonostratigraphic settings of units sampled at the deformed eastern margin of the Humber Arm Allochthon, relative to platformal sequence and the allochthon; see Figure 1 for Legend.*

the alternative view that the Pinchgut is part of the Humber Arm Allochthon.

The thrust-bounded Weasel group occurs to the north in the vicinity of Old Mans Pond and is situated structurally atop the platformal sequence (Williams *et al.*, 1982; Nyman *et al.*, 1984). It contains grey shale, thin-bedded limestone and carbonate conglomerate. The age and depositional setting of the unit are uncertain, since it displays similarities with both the Reluctant Head Formation and the (allochthonous) Northern Head group. The author collected poorly preserved ?Ordovician brachiopods this summer and samples are currently being processed for conodonts.

In a separate structural slice, red and green slates of the Canal Pond formation are clearly correlatives of the Summerside Formation. Nearby, black and grey shale and quartzitic sandstone of the Otter Brook formation, are similarly correlated with the Irishtown Formation. Likewise, black and grey shale and carbonate of the Bobby's Brook formation closely resemble the Northern Head group.

The Georges Lake formation (Williams and Cawood, 1986) separates the margin of the Humber Arm Allochthon from the structurally underlying platformal sequence. The Georges Lake formation comprises grey to black, pyritic shale and calcareous and quartzose siltstone and sandstone. Shaly mélange zones are prominent. The unit has been related to wildflysch sedimentation and deformation during emplacement of the Humber Arm Allochthon (Williams and Cawood, 1986).

SAMPLING

Areas of Sampling

Shale samples from all of the tectonostratigraphic units described above have been collected in eight principal geographic areas (Figure 4).

Port au Port Area. Samples were collected from the Table Head Group, the overlying Mainland formation and the structurally overlying Humber Arm Allochthon.

Bay of Islands Area (Humber Arm Allochthon). A large suite of samples spans the sedimentary sequence here, including the Summerside and Irishtown formations, but focussing on the Northern Head group and overlying Eagle Island formation. Mélange zones within the allochthon were also sampled, and altered shales (Middle Arm Point and Eagle Island formations) were collected from the base of the Bay of Islands ophiolite complex.

Humber Arm Area (Deformed margin of the Humber Arm Allochthon). Representative shale samples were collected from the variably deformed and metamorphosed units described above, from the Georges Lake area northward to the vicinity of Old Man's Pond (Figure 4).

Bonne Bay–Cow Head Area (Autochthonous sequence and Humber Arm Allochthon). The Lower Cambrian Forteau Formation and Middle Ordovician Goose Tickle Formation were examined and sampled in the Bonne Bay area. The basal mélange of the Humber Arm Allochthon was also sampled, and altered shale samples were collected from the base of the Bay of Islands ophiolite complex.

A suite of shale samples, spanning the Middle Cambrian to Middle Ordovician Cow Head Group has been assembled. These were collected from several stratigraphic sections, which include both proximal and distal depositional settings.

Table Point Area. The author sampled from a coastal section immediately north of Bellburns. This section contains excellent exposures of the Table Head Group and overlying flysch (Goose Tickle Formation).

Canada Bay Area. The margin of the Hare Bay Allochthon lies within this region. Deformation and metamorphism of platformal sediments increases progressively toward the margin of the allochthon, and sampling of platformal shales transects this gradient. Transported and platformal sediments were also sampled in the Main Brook area to the north.

Pistolet Bay–northern Hare Bay Area. Shale units and mélange zones of the Hare Bay Allochthon (Northwest Arm Formation, Maiden Point Formation, Milan Arm Mélange, Cape Onion Formation) and exposures of the Table Head Group and Goose Tickle Formation were sampled in this region.

Jackson's Arm Area (White Bay). Deformed and metamorphosed equivalents of parts of the lower Paleozoic carbonate sequence occur in the most easterly, 'external' setting in the Jackson's Arm area. Phyllitic units, commonly rich in pyrite, were sampled here.

Status of Samples

Samples collected and analysed prior to the 1987 field season, mostly from the Humber Arm Supergroup, provide major and trace element data for 160 samples; organic carbon–sulphur content has been determined for 97 of these. Major- and trace-element analyses of the 114 samples collected during 1987 are presently being conducted by the Newfoundland Department of Mines and organic carbon–sulphur analysis for all remaining samples is underway at the Geologic Survey of Canada.

In total, these analyses will provide a basic geochemical database of 274 shale samples. Subsets of this collection have been selected for sulphur isotope analysis and determination of illite crystallinity index (see below).

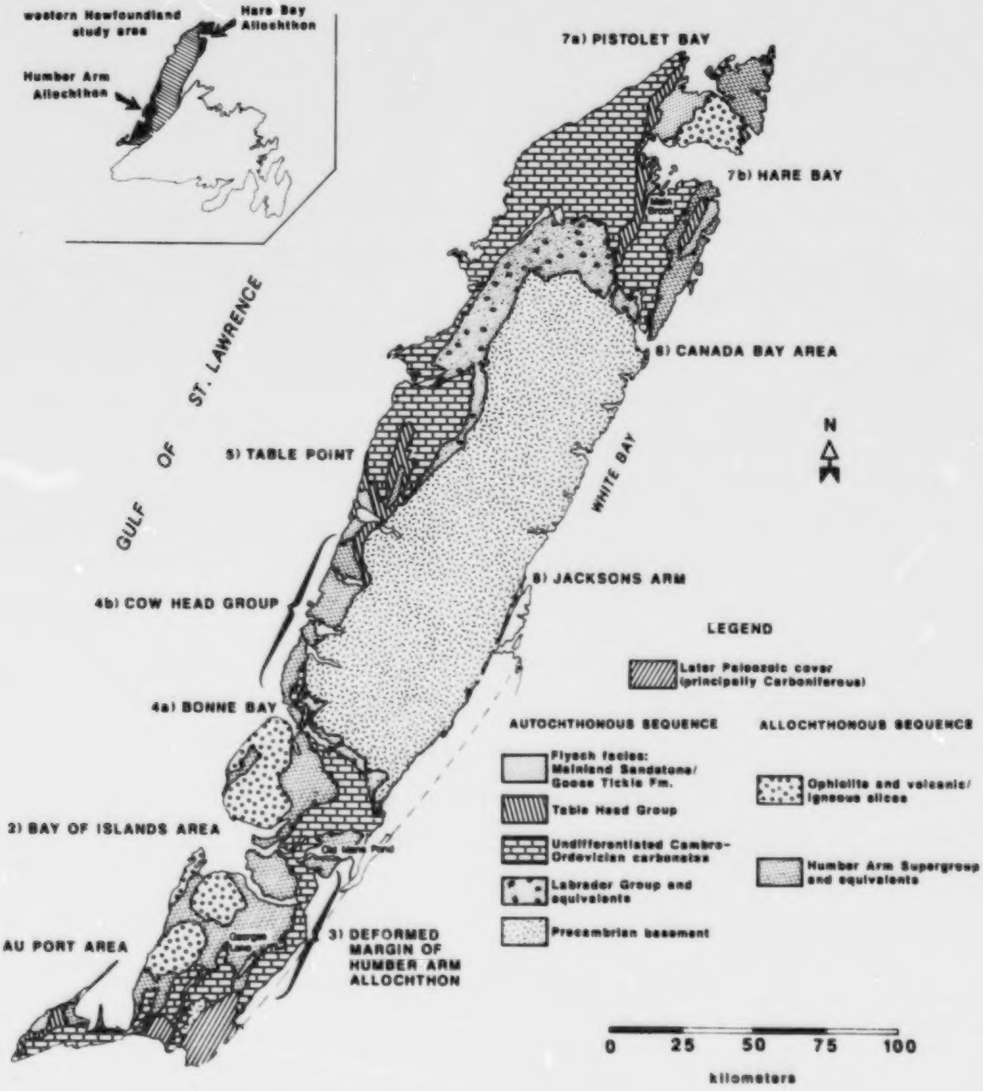

western Newfoundland
study area
Hare Bay
Allochthon
Humber Arm
Allochthon
7a) PISTOLET BAY
7b) HARE BAY
6) CANADA BAY AREA
WHITE BAY
N
GULF OF ST. LAWRENCE
5) TABLE POINT
8) JACKSONS ARM
4b) COW HEAD GROUP
4a) BONNE BAY
2) BAY OF ISLANDS AREA
1) PORT AU PORT AREA
3) DEFORMED
MARGIN OF
HUMBER ARM
ALLOCHTHON
LEGEND
Later Paleozoic cover
(principally Carboniferous)
AUTOCHTHONOUS SEQUENCE
Flysch facies:
Mainland Sandstone/
Goose Tickle Fm.
Table Head Group
Undifferentiated Cambro-
Ordovician carbonates
Labrador Group and
equivalents
Precambrian basement
ALLOCHTHONOUS SEQUENCE
Ophiolite and volcanic/
igneous slices
Humber Arm Supergroup
and equivalents
0
25
50
75
100
kilometers

Figure 4. *Generalized geology of western Newfoundland indicating the principal areas of sampling.*

INTERIM RESULTS

Variation in deep-water depositional–early diagenetic conditions and possible temporal oceanic changes

In the Bay of Islands area, the Humber Arm Supergroup records a marked change, in the late Tremadoc, from near-anoxic depositional and early diagenetic conditions to a better-oxygenated, suboxic setting in the Arenig. Near-anoxic conditions predominated from at least the late Middle Cambrian to the Late Tremadoc, and are characterized by: 1) relatively abundant organic carbon, 2) paucity of bioturbation, 3) absence of Mn and Ba in shale, 4) presence of early precipitated pyrite, and 5) apparent absence of ferric Fe compounds. All of these are consistent with the early onset of anoxic diagenetic conditions, at, or very close to the seafloor. These conditions spanned deposition of the Irishtown and Cooks Brook formations and are sharply transitional, through the base of the Middle Arm Point formation. The subsequent suboxic setting then prevailed during deposition of the the Middle Arm Point and Eagle Island formations. The suboxic setting is characterized by: 1) abundant bioturbation and diminished organic carbon, 2) widespread occurrence of diagenetic Mn-carbonate, 3) presence of hematite, and 4) the precipitation of authigenic barite within shale. These features are thought to reflect early diagenesis under redox gradients that existed at shallow depths in the sediment as a result of increased oxygen levels in the depositional environment (Botsford, 1987).

Whereas this Lower Ordovician transition into more oxidizing deep-water conditions is dramatic in the Northern Head group, the change is much more subdued in the Cow Head Group, where proximal facies are relatively rich in organic carbon throughout. This difference has been ascribed to variability in the carbonate margin and slope morphology, which influenced local paleoceanographic conditions, and resulted in the more extensive and continuous deposition of biogenic debris in the Cow Head area (Botsford, 1987).

Notwithstanding these lateral variations, the relative abundance of organic carbon within the Middle Cambrian to Lower Ordovician interval described above is consistent with a worldwide episode of extensive black mud deposition, suggestive of poorly aerated, deep-marine bottomwater (cf. Leggett *et al.*, 1981). Likewise, the appearance of more oxidizing conditions in the late Tremadoc of the Northern Head and Cow Head groups is roughly coincident with a widespread Lower Ordovician interval sparse in black shale, suggesting that it may reflect, in part, global oceanic conditions. This temporal change in oceanic conditions is of interest in this study, as it bears on the potential mobilization and precipitation of base metals in shales, and may be partly responsible for the distribution of sulphides discussed below.

The most widespread subsequent mud deposit is represented by the Middle Ordovician Black Cove Formation, which is generally well-laminated and relatively rich in organic carbon. This is consistent with deposition in restricted, fault-bounded basins created by differential collapse of the carbonate platform (Stenzel and James, 1987).

SULPHIDE OCCURRENCE AND BASE-METAL CONCENTRATIONS

Pyrite-rich Horizon at the Base of the Cooks Brook Formation (late Middle Cambrian)

Abundant pyrite characterizes the base of the Northern Head group (Irishtown–Cooks Brook formation boundary) and is particularly well developed at Middle Arm in the Bay of Islands. Here, over a roughly 10 m shale-dominated unit, several beds of what was originally carbonate-pebble conglomerate, ranging in thickness from 2 to 40 cm, are partially to completely replaced by pyrite (Plate 1). The only lithology that is never replaced is black, phosphatized shale, which comprises up to 10 percent of individual beds. Where replacement is complete, field textures suggest detrital pyrite, but petrographic examination indicates that this is a relatively fine-crystalline (30 micrometers), pebble-by-pebble replacement of an original carbonate host exhibiting interstitial ferroan carbonate cement. No associated base-metal sulphides were observed.

This pyrite-rich layer overlies a roughly 40-m-thick, black shaly unit at the top of the Irishtown Formation. This is indicative of widespread anoxic deep-water conditions, conducive to sulphate reduction and the resultant early precipitation of sulphides.

Plate 1. *Thin beds of carbonate conglomerate completely replaced by pyrite (py) within laminated black shale (sh); base of the Cooks Brook Formation (late Middle Cambrian), Middle Arm, Bay of Islands.*

Base-Metal Concentrations

Humber Arm Allochthon. The distribution of Zn, Pb, Cu and Ni concentrations in shale of the Northern Head and Cow Head groups is shown in Figure 5 and indicates the presence of anomalous concentrations of these metals in several samples. Individual metals occur in concentrations up to 300 ppm compared to 'background' values of 20 to 50 ppm. Preliminary results indicate that the stratigraphic distribution and nature of these anomalies differ between the Northern Head and Cow Head groups.

Northern Head Group

The stratigraphic distribution of Pb, Zn, Cu and Ni within the Northern Head group is shown in Figure 6 and indicates the pronounced enrichment of these metals in shales of Early Ordovician (Arenig) age at the base of, and within, the Eagle Island sandstone.

Petrographic and SEM/EDAX examinations of individual shale samples indicate the presence of chalcopyrite, galena, sphalerite and locally pentlandite, occurring as highly disseminated blebs and grains, 10 to 50 micrometers in size, and within very thin veinlets.

Sulphide blebs commonly demonstrate irregular, intergrown and locally replacive boundaries with the surrounding clay matrix. Intergrown galena–sphalerite and galena–chalcopyrite also occur in euhedral cubic habit (Plate 2), where they may have replaced pyrite. Where sulphides

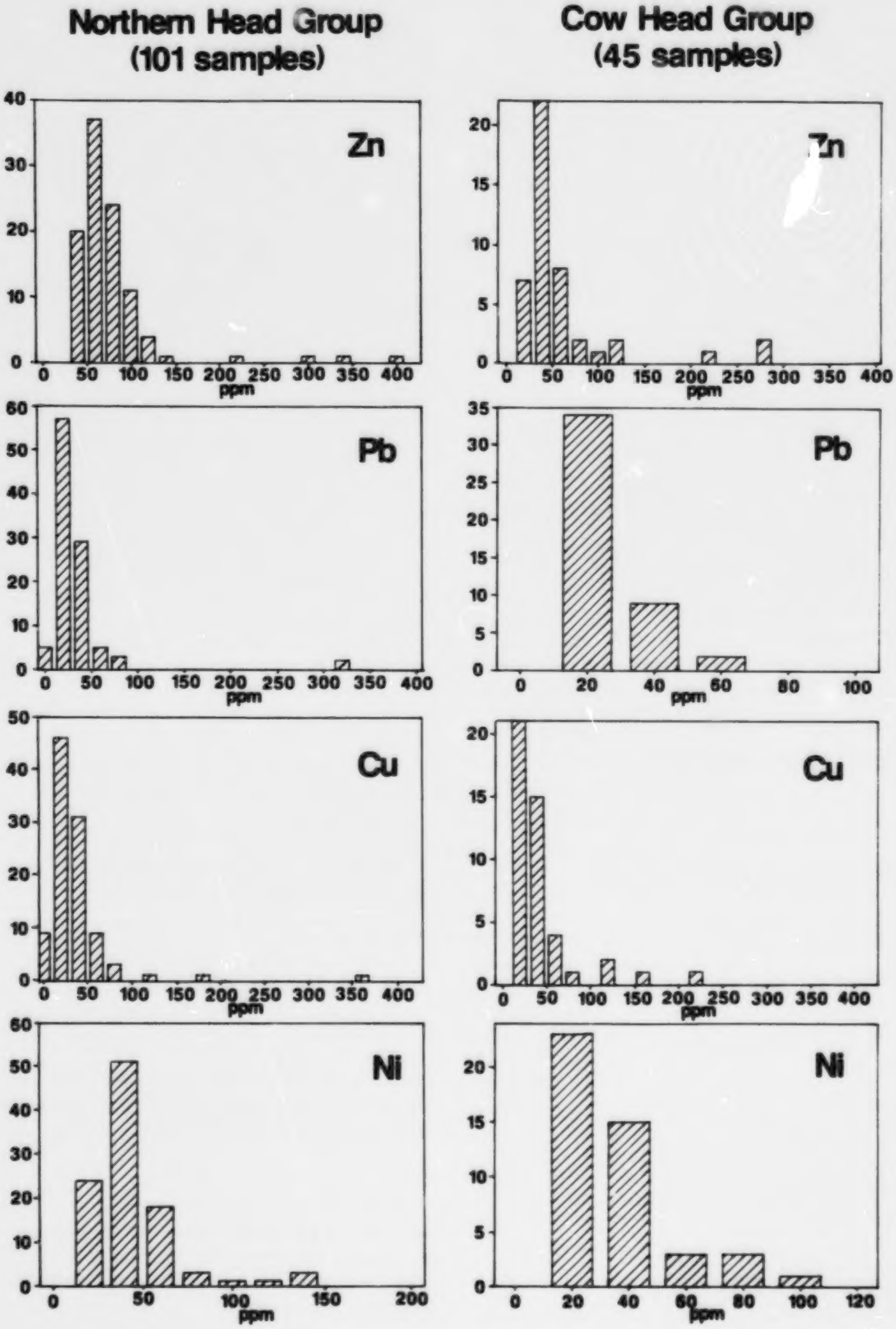


Figure 5. *The distribution of Zn, Pb, Cu and Ni in shale of the Northern Head and Cow Head groups within the Humber Arm Allochthon.*

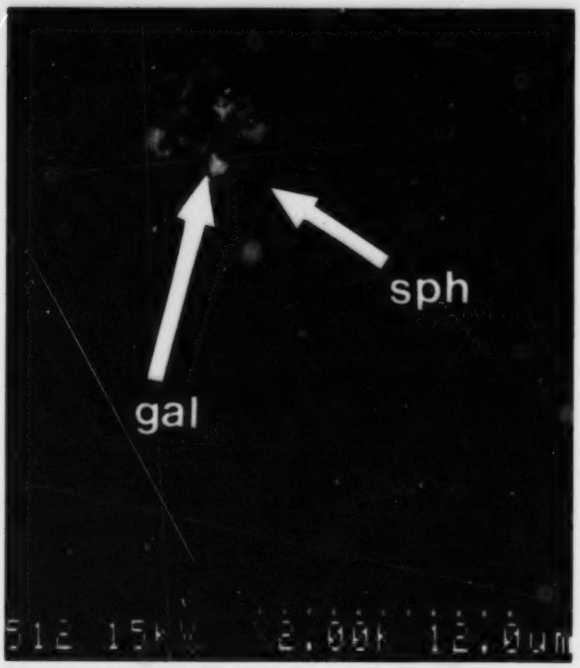


Plate 2. *SEM/EDAX photomicrograph (backscatter mode) illustrating intergrown galena (gal)/sphalerite (sph) grain within (opaque) shale matrix; Middle Arm Point formation, Bay of Islands area; magnification and scale in micrometers at lower right.*

have been noted within adjacent thin sandstones, they occur as late pore fillings, surrounding detrital grains and locally replacing interstitial matrix and cement (Plate 3).

Veinlets range up to 0.25 mm in width. Some contain galena, others, chalcopyrite. Both sulphides occur intergrown with vein-filling K-feldspar and quartz (Plate 4).

Cow Head Group

In contrast to the Northern Head group, zinc and copper anomalies within Cow Head Group shales are not concentrated at one stratigraphic horizon, but are scattered from the Upper Cambrian to the Lower Ordovician. Concentrations of lead and nickel are consistently low in shales of the Cow Head Group.

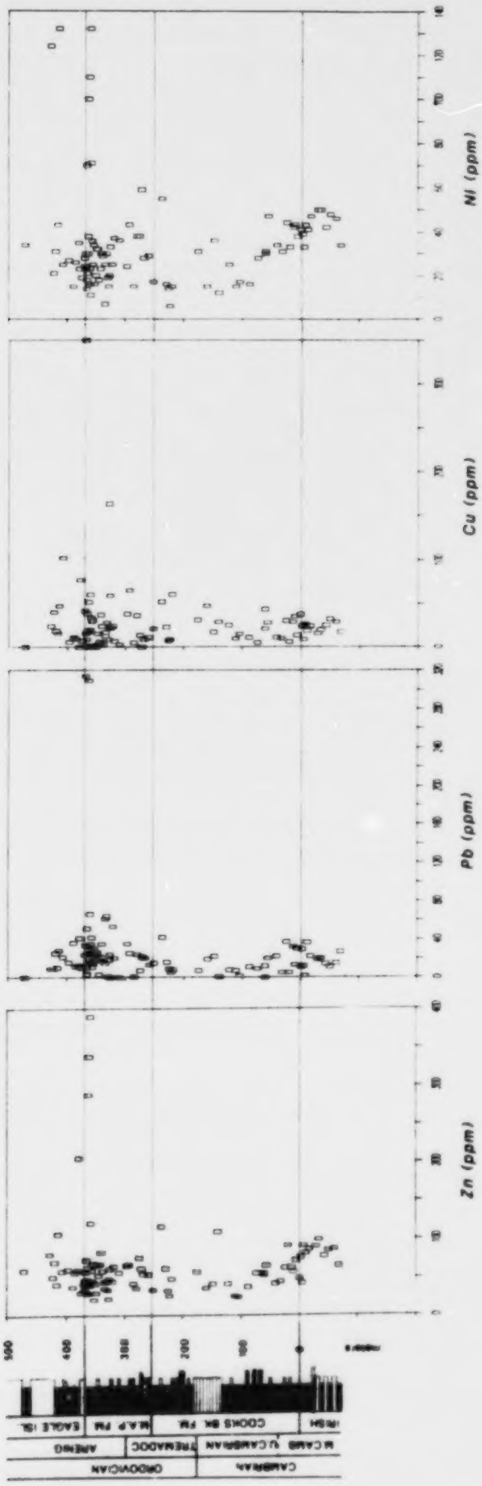


Figure 6. *Stratigraphic distribution of Zn, Pb, Cu and Ni within shale of the Northern Head group and adjacent units. The stratigraphic interval spans: 1) the Irishtown Formation, at the base, through 2) the Cooks Brook and Middle Arm Point formations (Northern Head group) and 3) the overlying Eagle Island sandstone. This diagram displays the anomalous concentration of these elements in sulphides localized at the base of the Eagle Island sandstone.*

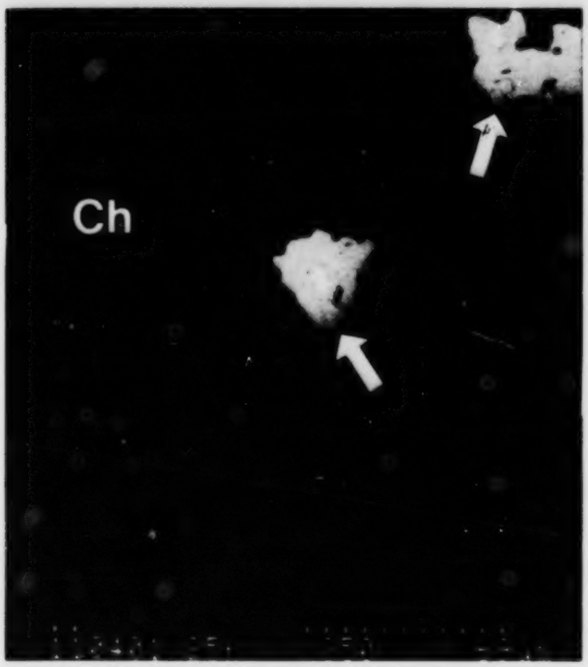


Plate 3. *SEM/EDAX photomicrograph (backscatter mode) illustrating pore-filling chalcopyrite blebs (arrows), with small inclusions of galena (bright areas), within thin sandstone bed at base of Eagle Island sandstone. Surrounding silicate grains are opaque in backscatter mode but adjacent detrital chromite grain (Ch) can be seen; Eagle Island formation, Bay of Islands area; magnification and scale in micrometers at lower right.*

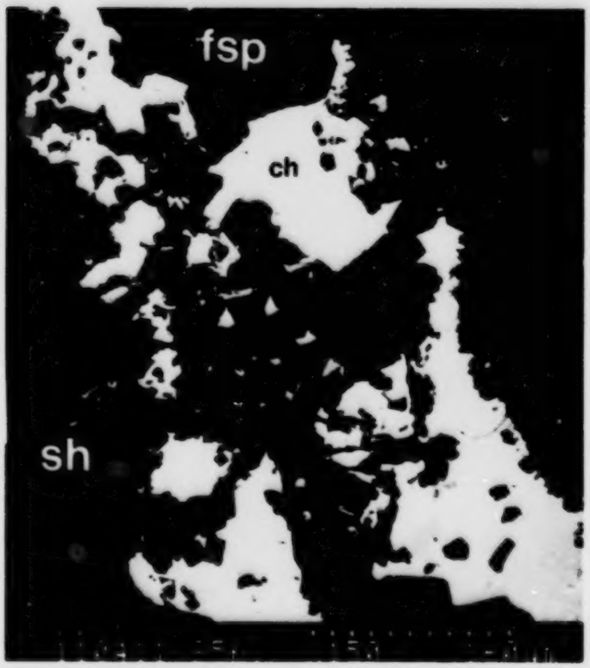


Plate 4. *SEM/EDAX photomicropgraph (scanning mode) of thin veinlet within Middle Arm Point formation shale illustrating intergrown chalcopyrite (ch) and K-feldspar (fsp) crosscutting shale matrix (sh); magnification and scale in micrometers at lower right.*

Although sulphides in these shales have not yet been well documented, sphalerite, chalcopyrite and ?pyrrhotite appear to be associated with delicate framboidal pyrite (Plate 5), which is, in turn, related to the presence of organic matter. All of these sulphides appear to have been precipitated relatively early in the diagenetic history of the shales. Copper and zinc anomalies are commonly associated with elevated concentrations of vanadium, which displays a good correlation with organic carbon content.

Existing trace element data comes from samples collected from the distal (depositional) portion of the Cow Head Group. The proximal, more organic carbon-rich facies was sampled during 1987.

Platformal Sequence: Black Cove Formation. Geochemical data presently available for shales of the Black Cove Formation has been provided by S. Stenzel. This unit was extensively sampled during 1987 and geochemical analyses are in progress. The data of Stenzel indicate anomalous concentrations of Zn (ranging from 200 to 366 ppm) in several Black Cove shales, from both the Port au Port and Pistolet Bay areas (Figure 4). These are all thinly laminated black shales with abundant siliciclastic and carbonate silt grains.

Sulphides are dominated by pyrite containing localized association of sphalerite. Pyrite occurs as disseminated subhedral to euhedral grains 10 to 30 micrometers in size and as interlocking masses of similar crystals, up to 2 mm in size (Plate 6). Sphalerite appears to occur generally as a replacement of pyrite, commonly close to the margin of interlocking masses (Plate 6). Precipitation of both sulphides appears to be relatively early, predating sediment compaction, and commonly localized by fragments of organic material.

Discussion

The mechanism of metal concentration in shale of the Northern Head group and Cow Head Group contrasts in timing and style. In the first case, precipitation of Zn, Cu, Pb and Ni(?) sulphides appears to have been a stratigraphically confined, relatively late event, through vein and pore filling and replacement, and not directly related to the presence of organic carbon. On the other hand precipitation in the Cow Head Group appears to have been relatively early and does not demonstrate evidence of extensive remobilization. This contrast in sulphide mineralization may be related to several factors.

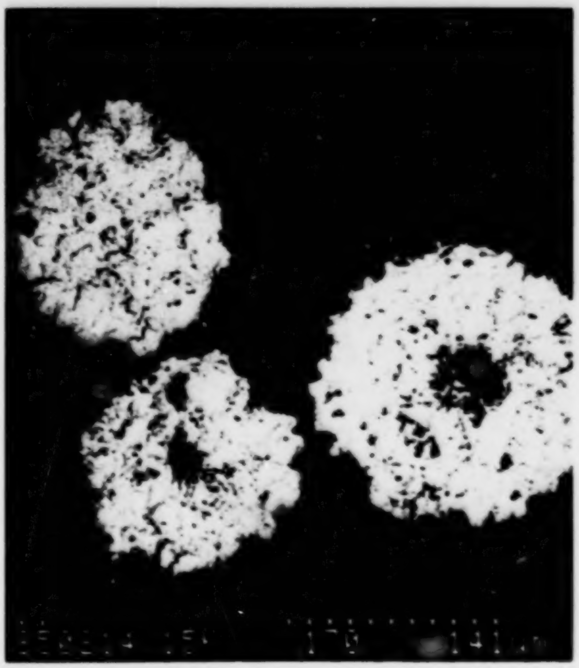


Plate 5. *SEM/EDAX photomicrograph (scanning mode) illustrating framboids comprising intergrown chalcopyrite and pyrrhotite within Cow Head Group shale; Western Brook Pond; magnification and scale in micrometers at lower right.*

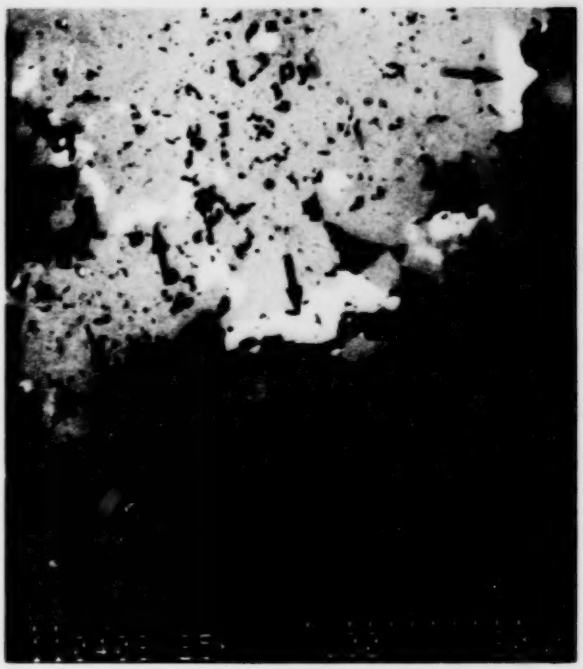


Plate 6. *SEM/EDAX photomicrograph illustrating interlocking mass of early-precipitated pyrite (py) with associated sphalerite (arrowed lighter areas) near margins; Black Cove Formation shale, Pistolet Bay area; magnification and scale in micrometers at lower right.*

The mobility of transition metals generally increases under oxidizing conditions, while reducing conditions generally result in precipitation as sulphides in the presence of reduced sulphur (Jacobs and Emerson, 1982; Maynard, 1983). Transport mechanisms may include the formation of complexes involving chloride or organic matter. Concentration of metals in organic material may commence during the life-cycle of organisms, and combined with the behaviour of these metals outlined above, is thought to account for the common association of sulphide mineralization with (organic-rich) black shale (Vine and Tourtelot, 1970; Calvert and Price, 1970; Maynard, 1983).

Preliminary evidence suggests that these processes of metal enrichment, related to the presence of organic carbon, controlled sulphide precipitation in Cow Head Group shales. This does not, however, appear to be the principal factor controlling the anomalous occurrence of Pb, Zn, Cu and Ni in the Northern Head group, since this enrichment appears in an interval that has undergone the most oxidizing depositional and early diagenetic conditions (as outlined above).

Factors responsible for this localized enrichment may include: 1) the transport of metals, within detrital grains or as complexes, during deposition of the Eagle Island sandstone, 2) the *in situ* mobilisation of metals during oxidizing-early diagenetic conditions (cf. Klinkhammer *et al.*, 1982), and 3) contrasting burial and deep-diagenetic history. Determination of illite crystallinity indices is directed toward assessing the last factor.

SULPHUR ISOTOPES

Samples selected for pyritic sulphur isotope determination are of known or readily inferred age and span the entire stratigraphic sequence under consideration. Temporal trends in sulphur isotopic signature may be used to identify episodes of oceanic stagnation having associated widespread reducing conditions, and ventilated, relatively oxidizing conditions. These may have been a factor in controlling base-metal mobility (cf. Goodfellow and Jonasson, 1984).

The nature of the sulphur reservoir present in bottom-water at any given time is most directly indicated by early diagenetic pyrite (or its metastable precursor), precipitated at the onset of bacterial sulphate reduction during shallow burial. Ensuing generations of pyrite tend to be coarser crystalline and more euhedral and may incorporate sulphur of uncertain isotopic history. A chemical technique recently developed at the Geological Survey of Canada (Hall *et al., in press)* facilitates the extraction, separation and sulphur isotope determination of highly disseminated, early precipitated pyrite like that in the shale samples of this study.

The majority of isotopic analyses are being carried out using samples most likely to contain pyrite of this type, but the isotopic signature of other styles of pyrite is also being determined for comparison.

The sulphur isotopic signature of authigenic barite from the Northern Head and Cow Head groups is also being determined.

ACKNOWLEDGMENTS

This project is undertaken in collaboration with D.F. Sangster, Geological Survey of Canada, who is thanked for his interest and support. I am grateful to P. Cawood and I. Knight for sharing their knowledge of western Newfoundland, and S. Stenzel for providing samples and unpublished geochemical data. This study incorporates sampling and analysis conducted by the writer during 1984 and 1985 that was supported by NSERC funding to N.P. James. Analyses of samples collected during 1987 is being done by the Newfoundland Department of Mines. I. Knight is thanked for critically reviewing this paper.

REFERENCES

Botsford, J.W.
1987: Depositional history of Middle Cambrian to Lower Ordovician deep-water sediments, Bay of Islands, western Newfoundland. Unpublished Ph.D. thesis, Memorial University of Newfoundland, 534 pages.

Calvert, S.E. and Price, N.B.
1970: Minor metal contents of recent organic-rich sediments off southwest Africa. Nature, Volume 227, pages 593-595.

Chow, N. and James, N.P.
1987: Cambrian Grand Cycles: A northern Appalachian perspective. Geological Society of America Bulletin, Volume 98, pages 418-429.

Erdtmann, B.D.
1971: Ordovician graptolite zones of western Newfoundland in relation to paleogeography of the North Atlantic. Geological Society of America Bulletin, Volume 82, pages 1509-1528.

Goodfellow, W.D. and Jonasson, I.R.
1984: Ocean stagnation and ventilation defined by $\delta^{34}S$ secular trends in pyrite and barite, Selwyn Basin, Yukon. Geology, Volume 12, pages 583-586.

Hall, G.E.M., Pelchat, J. and Loop, J.
In press: Separation and recovery of various sulphur species in sedimentary rocks for stable isotope determination. Chemical Geology.

Jacobs, L. and Emerson, S.
1982: Trace metal solubility in an anoxic fjord. Earth and Planetary Science Letters, Volume 60, pages 237-252.

James, N.P. and Stevens, R.K.
1982: Anatomy and evolution of a lower Paleozoic continental margin, western Newfoundland. 11th International Congress on Sedimentology, Field Excursion Guidebook 2B.

1986: Stratigraphy and correlation of the Cambro-Ordovician Cow Head Group, western Newfoundland. Geological Survey of Canada, Bulletin 366, 143 pages.

Klappa, C.F., Opalinski, P.R. and James, N.P.
1980: Middle Ordovician Table Head Group of Western Newfoundland: a revised stratigraphy. Canadian Journal of Earth Sciences, Volume 17, pages 1007-1019.

Klinkhammer, G., Heggie, D.T. and Graham, D.W.
1982: Metal diagenesis in oxic marine sediments. Earth and Planetary Science Letters, Volume 61, pages 211-219.

Knight, I. and Boyce, W.D.
1987: Lower to Middle Cambrian terrigneous-carbonate rocks of Chimney Arm, Canada Bay: lithostratigraphy, preliminary biostratigraphy and regional significance. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 87-1, pages 359-365.

Knight, I. and James, N.P.
1987: The stratigraphy of the Lower Ordovician St. George Group, western Newfoundland: the interaction between eustasy and tectonics. Canadian Journal of Earth Sciences, Volume 24, pages 1927-1951.

Leggett, J.K., McKerrow, W.S., Cocks, L.R.M. and Richards, R.B.
1981: Periodicity in the early Paleozoic marine realm. Journal of the Geological Society of London, Volume 138, pages 167-176.

Lilly, H.D.
1963: Geology of the Hughes Brook—Goose Arm Area, Western Newfoundland. Memorial University of Newfoundland, Department of Geology, Report No. 2, 123 pages.

Maynard, J.B.
1983: Geochemistry of sedimentary ore deposits. Springer-Verlag, New York, 305 pages.

Nyman, M., Quinn, L., Reusch, D.N. and Williams, H.
1984: Geology of Lomond map area, Newfoundland. *In* Current Research, Part A. Geological Survey of Canada Paper, 84-1A, pages 157-164.

Ross, R.J. and James, N.P.
1987: Brachiopod biostratigraphy of the middle Ordovician Cow Head and Table Head groups, western Newfoundland. Canadian Journal of Earth Sciences, Volume 24, pages 70-95.

Saunders, C.M. and Strong, D.F.
1986: Assessment of lead-zinc deposits of the western Newfoundland carbonate platform. *In* Current Research, Part A. Geological Survey of Canada, Paper 86-1A, pages 229-237.

Stenzel, S.R. and James, N.P.
1987: Death and destruction of an early Paleozoic carbonate platform, western Newfoundland. (Abs.) Society of Economic Paleontologists and Mineralogists Mid-Year Meeting, Austin.

Stevens, R.K.
1970: Cambro-Ordovician flysch sedimentation and tectonics in west Newfoundland and their bearing on a proto-Atlantic Ocean. Geological Association of Canada, Special Paper No. 7, pages 165-177.

Tuke, M.F.
1968: Autochthonous and allochthonous rocks in the Pistolet Bay area in northernmost Newfoundland. Canadian Journal of Earth Sciences, Volume 5, pages 501-513.

Vine, J.D. and Tourtelot, E.B.
1970: Geochemistry of black shale deposits—a summary report: Economic Geology, Volume 65, pages 253-272.

Williams, H.
1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 16, pages 792-807.

Williams, H. and Cawood, P.A.
1986: Relationships along the eastern margin of the Humber Arm Allochthon between Georges Lake and Corner Brook, western Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 86-1A, pages 759-765.

Williams, H., Gillespie, R.T. and Knapp, D.A.
1982: Geology of Pasadena map area, Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 82-1A, pages 281-288.

Williams, H., James, N.P. and Stevens, R.K.
1985: Humber Arm Allochthon and nearby groups between Bonne Bay and Portland Creek, western Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 85-1A, pages 399-406.

Williams, H. and Smyth, W.R.
1983: Geology of the Hare Bay Allochthon. Geological Survey of Canada, Memoir 400, pages 109-133.

Current Research (1988) Newfoundland Department of Mines,
Mineral Development Division, Report 88-1, pages 99-107

GEOLOGY OF THE PUDDLE POND (12A/5) AND LITTLE GRAND LAKE (12A/12) MAP AREAS, SOUTHWESTERN NEWFOUNDLAND

J.T. van Berkel[1] and K.L. Currie
Lithosphere and Canadian Shield Division
Geological Survey of Canada

ABSTRACT

The Puddle Pond and Little Grand Lake map areas consist of four diverse terranes separated by major high-strain zones. Northwest of the Long Range Fault, late Precambrian metasedimentary rocks and unconformably underlying gneiss (Steel Mountain terrane) are thrust to the northwest to form duplex structures. Between the Long Range and Victoria Lake faults, leucocratic and nebulitic to stromatic quartzofeldspathic to pelitic gneisses of uncertain age (Central Gneiss terrane) are invaded by mafic intrusions and a variety of granitoid rocks. Basalt, felsic volcanics and sedimentary rocks of the Victoria Lake Group in the Victoria Lake terrane experienced very mild metamorphism. North of the Little Grand Lake Fault, the Topsails terrane consists of little metamorphosed volcanic–sedimentary rocks of the Ordovician Glover group and distinctive granites.

The Long Range and Victoria Lake faults exhibit major early ductile deformation, late minor brittle movement, and a complex movement history. The Little Grand Lake Fault appears to be a southward-directed thrust with a small ductile component. Foliated granitoid rocks occur only in the Central Gneiss terrane. Mafic intrusions appear to be controlled by the major faults, but do not occur northwest of the Long Range Fault.

INTRODUCTION

The Puddle Pond (12A/5) and Little Grand Lake (12A/12) map areas form part of the Long Range uplands, a rolling surface that has been deeply dissected by erosion. Outcrop is good on the upland barrens, except in areas of stunted-spruce growth ('tuckamore'), but poor to nonexistent in the valleys. Highway 480 (the Burgeo road) crosses the Puddle Pond map area, and other woods roads, as well as Grand Lake and Little Grand Lake, provide access to parts of the area. However, easy access to much of the region can only be obtained by aircraft.

This region has been investigated by 1:250,000 geological mapping (Riley, 1957). Herd and Dunning (1979) and Dunning (1984) mapped part of the Puddle Pond sheet at 1:50,000, and Whalen and Currie (1983a,b), Knapp (1982) and Kennedy (1981) have mapped parts of the Little Grand Lake sheet. The present work was undertaken as part of a systematic mapping program of the southern Long Range uplands (van Berkel *et al.*, 1986; van Berkel and Currie, 1986; Currie, 1986, 1987; van Berkel, 1987a,b,c).

GENERAL GEOLOGY

The mapped area (Figure 1) falls into four diverse geological terranes that are separated by major faults (van Berkel *et al.*, 1986). Northwest of the Long Range Fault, late Precambrian metasedimentary rocks and underlying Grenvillian gneisses of the Steel Mountain terrane (van Berkel *et al.*, 1986) have been thrust to the northwest. This region fits well into the Humber tectonostratigraphic zone of Williams (1979). Between the Long Range Fault and close to the Victoria Lake Fault, the rocks consist of quartzofeldspathic to semipelitic and calcareous gneisses invaded by mafic and granitoid intrusions. This Central Gneiss terrane (van Berkel *et al.*, 1986) does not resemble either the Humber or Dunnage zones of Williams (1979) but has some similarities to the Gander Zone. A narrow strip, forming the Victoria Lake terrane, between the Annieopsquotch Complex and the Victoria Lake Fault consists principally of low-metamorphic-grade mafic and felsic volcanic rocks of the Victoria Lake Group (see also Kean, 1983), a typical Dunnage Zone assemblage. North of the Little Grand Lake Fault, the Topsails terrane comprises very low-metamorphic-grade mafic and

---

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989. Project carried by Geological Survey of Canada: Project 850017

[1] Present address: Institute of Earth Sciences, Free University, P.O. Box 7161, 1007 MC Amsterdam, The Netherlands.

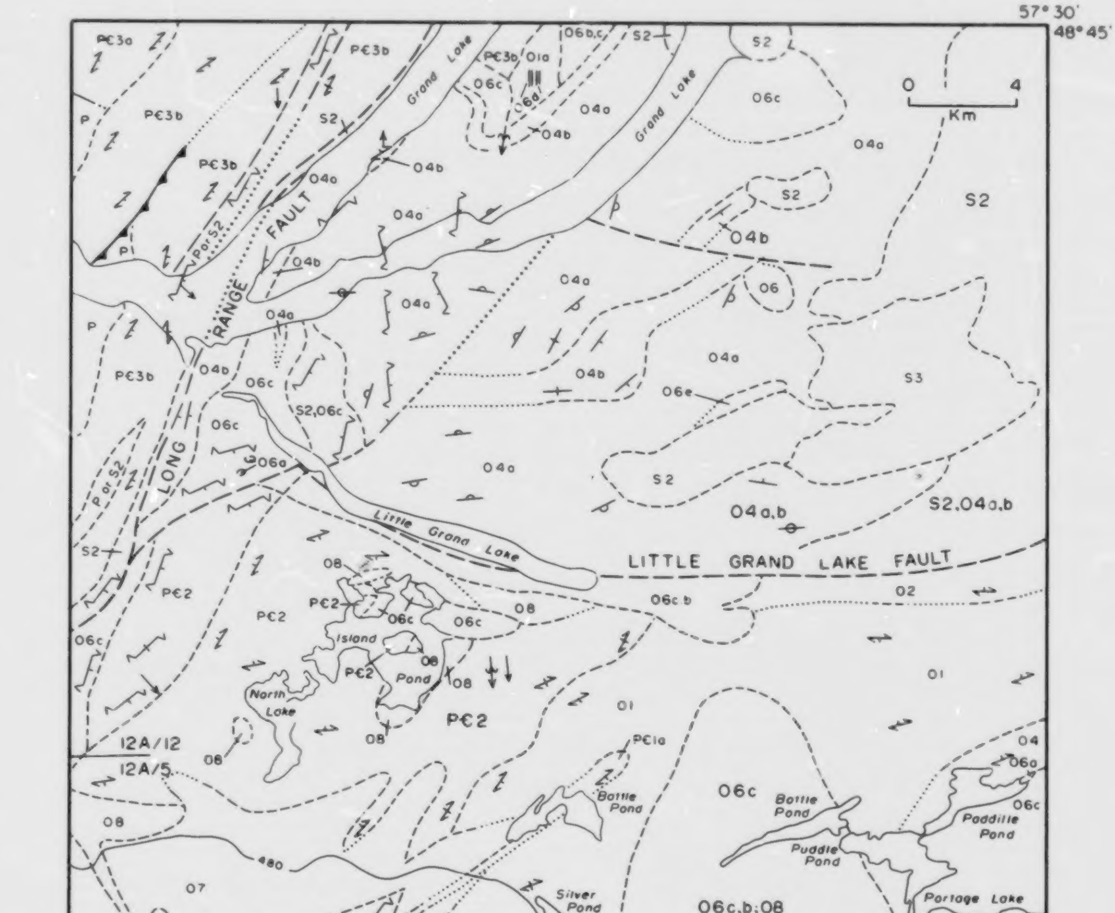
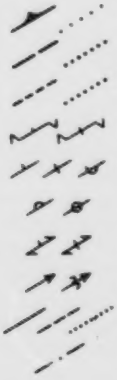

57° 30'
48° 45'
48° 15'
58° 00'
0
4
Km
LONG RANGE FAULT
LITTLE GRAND LAKE FAULT
VICTORIA LAKE FAULT
ANNIEOPSQUOTCH COMPLEX
Grand Lake
Little Grand Lake
Island Pond
North Lake
Bottle Pond
Puddle Pond
Paddille Pond
Portage Lake
Silver Pond
Southwest Brook Pond
Lloyds Lake
Victoria Lake
Cormacks Lake
12A/12
12A/5
480
PЄ3a
PЄ3b
P
P or S2
PI
PЄ2
PЄ1a
PЄ1b
PЄ1c
PЄ1d
S2
S3
S2,O6c
S2,O4a,b
O1
O1a
O2
O4
O4a
O4b
O4a,b
O5a
O5b
O6
O6a
O6b
O6c
O6d
O6e
O6b,c
O6c,b
O6c,a
O6c,d
O6c,d,b
O6c;O8
O6c,b;O8
O7
O8
O8,O6b
D
S1a
S1b

Figure 1. *Generalized geological map of the Puddle Pond (12A/5) and Little Grand Lake (12A/12) map areas, southwest Newfoundland. Note that, except where constrained by fossil or radiometric dates, all ages are tentative.*

LEGEND

DEVONIAN	
D	Windsor Point Group: *grey sandstone, grit, mudstone, conglomerate (Emsian fossils, ca. 372 Ma)*
SILURIAN	
S3	*peralkaline granite (429 ± 5 Ma)*
S2	*mostly unfoliated hornblende and/or biotite granite, often with porphyritic feldspar*
S1	a, *red sandstone and conglomerate;* b, *rhyolite (431 ± 5 Ma)*
ORDOVICIAN OR YOUNGER	
O8	*mostly unfoliated biotite granite and leucogranite, locally with porphyritic feldspar*
O7	*massive, locally flow-banded quartz diorite and tonalite*
O6	composite mafic intrusions: a, *dunite, harzburgite, pyroxenite, olivine gabbro;* b, *medium- to coarse-grained gabbro;* c, *medium grained diabase;* d, *fine grained diabase dyke;* e, *leucogabbro – diabase (Colour Index = 20-30)*
ORDOVICIAN	
O5	Victoria Lake Group (462 ± 4 Ma): a, *basalt;* b, *felsic volcanics and sediments (with intrusions of subunit O6c)*
O4	Glover group (ca. 480 Ma): a, *pillow basalt (with intrusions of subunit O6b to Unit O3);* b, *felsic volcanics (ash tuff, minor crystal tuff), minor shale and conglomerate*
O3	Ophiolite (?): a, *serpentinized dunite and harzburgite;* b, *pyroxenite;* c, *coarse grained metagabbro and amphibolite*
ORDOVICIAN OR OLDER	
O2	*mostly foliated biotite granite and leucogranite, locally with porphyritic feldspar*
O1	*foliated granodiorite – tonalite with abundant mafic inclusions*
UPPER PROTEROZOIC TO CAMBRIAN	
PC3	Fleur de Lys Supergroup: a, *phyllite, calcareous phyllite and marble;* b, *actinolite (± garnet) schist, marble, pelitic quartzite and quartzite*
PC2	Higher-grade metamorphic equivalents of the Fleur de Lys Supergroup (?): *nebulitic to stromatic quartzofeldspathic and semipelitic gneisses*
PC1	Cormacks Lake complex: a, *leucocratic quartzofeldspathic gneisses;* b, *with pyrite, gedrite ± garnet-bearing layers and minor pelitic and quartzitic rocks;* c, *amphibolite and coarse grained metagabbro (part of subunit O3c?);* d, *granulite*
UPPER PROTEROZOIC (Grenvillian)	
P	*intermediate and granitic gneisses; minor amphibolite*

SYMBOLS



thrust fault (approximate, assumed)

major fault (approximate, assumed)

minor fault (approximate, assumed)

shear zone (inclined, vertical)

bedding (inclined, vertical, overturned)

orientation of pillows in basalt (inclined, vertical)

foliation (inclined, vertical)

lineation; mesoscopic multiple folding

geological boundary (defined, approximate, assumed)

unconformity (approximate)

Geology by J.T. van Berkel, 1985-1987; K.L. Currie and M.A.J. Piasecki, 1985, 1986; H.P. Johnston, J. Martin and S. Dawson, 1985; and D. Machin and D. Fox, 1987. Partly after Herd and Dunning (1979); Kennedy, (1981); Knapp (1982); Whalen and Currie (1983a,b) and Dunning (1984).

felsic volcanic rocks of the Glover group, typical of the Dunnage Zone, and massive, commonly peralkaline, high-level granitic rocks that define the unique character of this terrane.

DESCRIPTION OF ROCK UNITS

Steel Mountain Terrane

South of Grand Lake, the oldest rocks consist of granitic to intermediate gneisses, minor amphibolite and rare quartzite beds (Unit P). These gneisses are unconformably overlain by metasedimentary cover rocks (Unit PC3) consisting of actinolite (± garnet) schist, marble, calcareous phyllite, pelitic quartzite (with staurolite + garnet assemblages) and quartzite. Some details of the stratigraphy and petrography of this sequence are given by Currie (1986), who followed earlier workers in correlating it with the upper Precambrian–lower Paleozoic Fleur de Lys Supergroup (Knapp *et al.*, 1979; Kennedy, 1981; Hibbard, 1983a,b; Williams, 1985).

The gneissic basement and its metasedimentary cover have been thrust to the northwest, forming spectacular duplexes in which the basement–cover unconformity is repeated several times (Currie, 1987). The thrust deformation has variably overprinted the fabric of the gneisses, producing new growth of oriented micas (Currie, 1987), and grain-size reduction of feldspar, quartz and amphibole. The degree of overprinting is generally low, but locally high enough to produce fissile schists in which the older gneissosity is destroyed. Sheets of very fissile, two-mica granitoid schists often found in the thrust zones may have been produced by such overprinting, in combination with alkali loss, rather than by synkinematic intrusion as suggested by Currie (1987).

Currie (1987) has shown that west of the Little Grand Lake (12A/12) map area, the gneisses of Unit P are younger than the Steel Mountain anorthosite and two-pyroxene granulites of the Disappointment Hill complex. A posttectonic peralkaline granite at Hare Hill gave a U–Pb date on zircon of 617 ± 8 Ma. Given these constraints, it seems reasonable to identify the metamorphism of the gneisses of Unit P as Grenvillian in age, that is ca. 1000 Ma.

Central Gneiss Terrane

The oldest rocks of the Central Gneiss terrane consist of quartzofeldspathic gneisses of the Cormacks Lake complex (Unit PC1) and quartzofeldspathic to semipelitic and calcareous gneisses of Unit PC2.

The Cormacks Lake complex (Herd and Dunning, 1979; van Berkel, 1987a) contains banded rocks with pyrite + gedrite ± garnet and minor pelitic and quartzitic rocks (subunit PC1b), and thick layers, lenses and inclusions of amphibolite (Plate 1; Figure 1) and coarse grained metagabbro (subunit PC1c). Some of the amphibolite exhibits relict igneous textures that could mean it represents metamorphosed remnants of ophiolite complexes (Unit 03). The predominant quartzofeldspathic gneiss was formerly interpreted as deformed biotite granite (van Berkel, 1987a), but a more detailed examination showed that the least deformed portions have a granoblastic texture (Plate 2), which is characteristic of statically recrystallized gneisses formed during medium- to high-grade metamorphism. An elongated hill north of Cormacks Lake consists of a slightly retrograded, two-pyroxene granulite (subunit PC1d). The Cormacks Lake complex may consist of a deformed basement–cover complex. Early tight folding is commonly obliterated by a gneissose banding, which is itself folded to give a map pattern showing macroscopic folds.

Plate 1. *Amphibolite inclusions in quartzofeldspathic gneisses of the Cormacks Lake Complex (subunit PC1a). Note the L–S fabric with lineation parallel to hammer. Outcrop in the Lloyds River, 5 km east of Cormacks Lake. GSC 204461.*

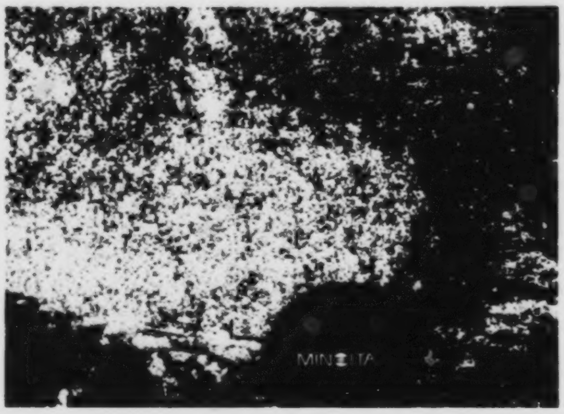


Plate 2. *Granoblastic quartzofeldspathic gneisses of the Cormacks Lake Complex (subunit PC1a). Location 8 km northeast of Cormacks Lake.*

Quartzofeldspathic and semipelitic gneisses (Unit PC2) form stromatic to nebulitic migmatites, but are clearly developed from a supracrustal sedimentary sequence, as indicated by the presence of quartzitic and calcareous beds. The gneisses form an extension of the metasedimentary gneisses in the Main Gut (12B/8) and Dashwoods Pond (12B/1) map areas, where they appear to be possibly correlative with the Fleur de Lys Supergroup northwest of the Long Range Fault. Unlike the Cormacks Lake complex, the gneisses of Unit PC2 are openly folded on a mesoscopic scale. Numerous small veins of biotite granite (Plate 3) form a characteristic feature of this unit. A thin layer and an inclusion of serpentinite were observed in this unit east of North Lake.

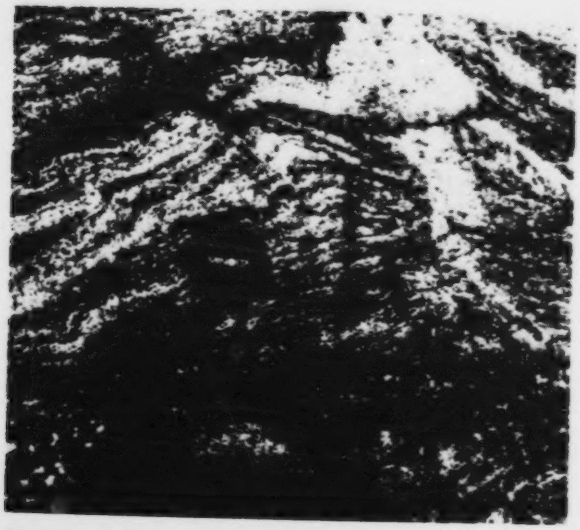


Plate 3. *Nebulitic to stromatic gneiss (Unit PC2). Note the crosscutting granitic veins. Location northeast corner of the Puddle Pond map area (12A/5). GSC 204460-U.*

The region from Padille Pond to Battle Pond is predominantly underlain by granitoid rocks ranging from medium- to coarse-grained, foliated biotite granite and leucogranite (Unit O2) to a distinctive, mafic-enclave-rich, foliated granodiorite–tonalite (Unit O1). This large region probably includes several plutons of uncertain age.

Intrusions of massive to slightly foliated, medium grained, diabasic gabbro and coarse grained, leucocratic gabbro (Unit O6; Plate 4) are cut by fine grained diabase dykes (Plate 5), tend to trend northeast or east-west, and are bounded by faults. Although these bodies locally contain enclaves of dunite (Plate 6), harzburgite or pyroxenite, they can be readily differentiated from remnants of ophiolites (Unit O3) by lack of deformation and associated ophiolitic units (ultramafic rocks, sheeted dykes, pillow lavas), common presence of minor amounts of biotite and local presence of lamprophyric texture. Mapping of the large body around Bottle Pond is hampered by poor exposure, but road and powerline exposures suggest a complex mixture of mafic phases including many dykes and granitoid enclaves (Units O1 and O2) and intrusions (Unit O8). H. Miller (personal communication, 1986) found a large positive Bouguer anomaly in this region, which can be modelled by assuming about 70 percent mafic rocks of density 2.9 g/cm^3 to a depth of 8 km (M.D. Thomas, personal communication, 1987).

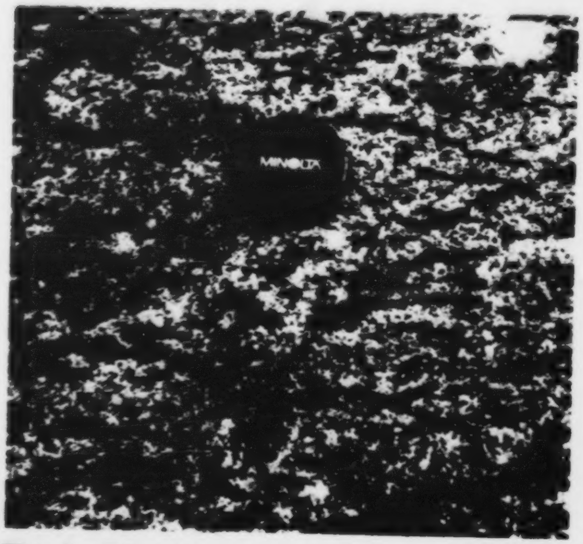


Plate 4. *Foliated, leucocratic, medium- to coarse-grained gabbro (subunit O6b). Location 3 km southwest of Silver Pond. GSC 204461-B.*

Plate 5. *Fine grained diabase dyke in medium grained diabase. Location 4 km northeast of Island Pond. GSC 204460-Z.*

The large Annieopsquotch Complex has been generally interpreted as an ophiolite (Dunning, 1984, 1987; Dunning and Herd, 1980; Dunning and Chorlton, 1985). However, our

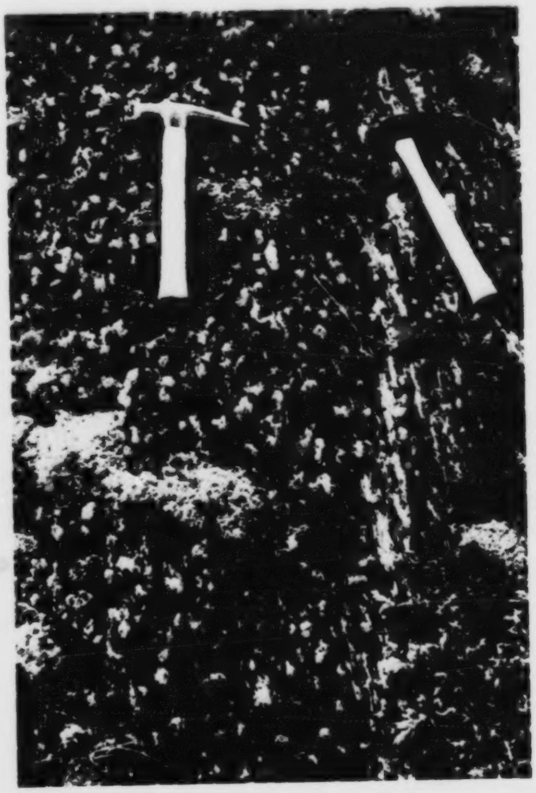


Plate 6. *Serpentinized dunite (subunit O6a) with chlorite-rich aggregates and a weak cleavage (white). Location 3 km southwest of Silver Pond. GSC 204461-E.*

re-examination shows that the ultramafic portions form small pods in a gabbroic matrix, that the dykes of the complex cut a gabbroic matrix, and that other lithologies typical of complete ophiolite complexes are notably absent. We therefore suggest that the Annieopsquotch Complex is not ophiolitic but is a postobduction mafic complex emplaced under a sinistral shear regime. This explains the 160-200° orientation of the dykes.

A large intrusion of quartz diorite and tonalite (Unit O7) outcrops along the Burgeo road (Route 480). The rocks contain inclusions of diabase and gabbro thought to be derived from Unit O6, and are cut by granite veins. A faint mineral banding and alignment of inclusions may be due to flow processes.

The youngest intrusive rocks (Unit O8) comprise massive medium grained biotite granite and leucogranite that cut all the previous units. Large intrusions of this type occur south of Southwest Brook Pond and west of Lloyds Lake.

Silurian red sandstone, conglomerate and rhyolite (Unit S1) unconformably overlie gabbro (Unit O6) and basalt of the Victoria Lake Group (Unit O5) in the southern part of the map area (Chandler, 1982; Chandler and Dunning, 1983). Devonian sedimentary rocks of the Windsor Point Group (Unit D) unconformably overlie this unit and also unfoliated biotite granite of Unit O8.

Victoria Lake Terrane

The Victoria Lake terrane lies between the Annieopsquotch Complex and the Victoria Lake Fault, a major structure that may be part of the Cape Ray fault system. The dominant rock unit in this area is the Victoria Lake Group (Unit O5) which consists of basalt, felsic volcanic rocks, and intercalated sedimentary rocks with numerous diabase dykes and sills (H. Williams, personal communication, 1987). Zircons from rhyolite of the Victoria Lake Group gave an age of 462 $^{+2}_{-4}$ Ma (Dunning *et al.*, 1987). Southeast of the fault, a strongly foliated granite and migmatite complex has been tentatively correlated with Unit O2. It appears to be similar to the Central Gneiss terrane.

Topsails Terrane

Much of the Topsails terrane (Whalen and Currie, 1983a,b) in the Little Grand Lake map area is underlain by well preserved, locally pillowed (Plate 7), basalt of the Glover group (Unit O4). Several layers of felsic volcanic rocks and sedimentary rocks, and one 15-m-thick layer rich in hematite were observed in the basalt. Intrusions of gabbro–diabase (subunits O6b,c,d) and Silurian granite (Units S2 and S3; Whalen *et al.*, 1987) are common. A late phase of east- to west-striking mafic dykes cuts the granites (Unit S2) east of Little Grand Lake.

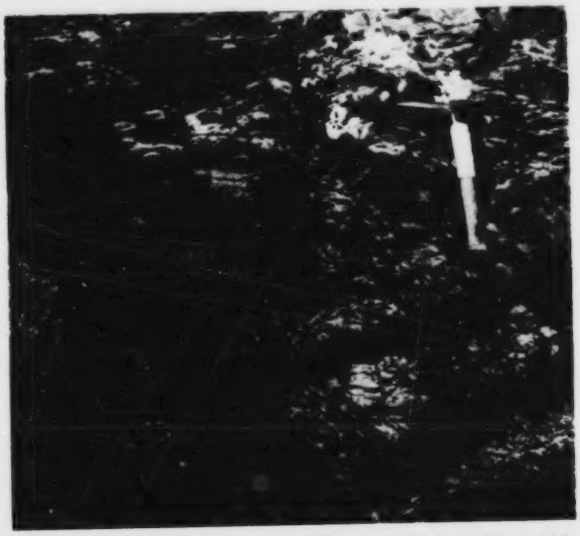


Plate 7. *Pillow basalt in the Glover Group (subunit O4). Location 7 km east of Little Grand Lake. GSC 204461-A.*

The transition from the Topsails terrane to the Steel Mountain terrane on Glover Island occupies a zone 0.5 to 1 km wide comprising highly deformed, felsic volcanic rocks and sedimentary rocks(?) of the Glover Group (Unit O4), two mafic intrusions (subunits O6b,c) and north-trending diabase dykes (subunit O6d), which cut the ophiolitic (Knapp, 1982) serpentinite of Unit O3. This transition clearly lies in a roughly north-south-striking deformation zone, which overprints and folds all earlier fabrics, foliates the mafic intrusions (subunits O6b,c) and crosscuts geological boundaries. The origin of this zone is not presently understood, but the structural character of the metasedimentary and volcanic rocks of Unit O4b suggest a dextral component of shear in this region.

ECONOMIC GEOLOGY

Rusty quartzofeldspathic rocks of the Cormacks Lake complex (subunit PC1b) contain a few percent pyrite and magnetite, but no detectable Au, Pt and Pd, even in large shear zones.

Ultramafic and mafic rocks of Unit O6 contain up to 9 ppb Au, 10 ppb Pt and 9 ppb Pd. Fissile zones with macroscopically visible pyrite contain up to 50 ppb Au.

DISCUSSION

Much of the southern Long Range uplands consist of amphibolite-grade metamorphic rocks derived from supracrustal protoliths, minor layers of highly deformed mafic to ultramafic rocks (Fox and van Berkel, *in press*), and pervasive granitoid plutonism. The derivation of the supracrustal rocks is not definitely known, but the rock types strongly suggest that they represent units of the Humber Zone northwest of the Long Range Fault. Lithologies of Unit PC3, presumed to be correlative with the Fleur de Lys Supergroup, can be correlated with many of the lithologies of Unit PC2 south of the fault. The Cormacks Lake complex, with its contained granulites, correlates well with the older gneisses (Unit P), which rest on granulite northwest of the fault. The presence of late Precambrian granitoid plutons has not been proved in the Central Gneiss terrane, but their presence in the Steel Mountain terrane suggests the possibility. In sum, the present work suggests that North American crust extended as far southeast as the Victoria Lake Fault.

The nature of the event that sutured this crust to other zones of Newfoundland during the Ordovician remains unclear. Brown (1976), Dunning (1984) and Dunning and Chorlton (1985) argued that large slices of ocean crust were emplaced in this region, and subsequently deformed and intruded. We find this highly improbable since the large mafic complexes such as the Annieopsquotch and those around Bottle Pond are essentially unaltered and undeformed. We feel they must be younger than the closure. Dunning and Krogh (1985) reported two Early Ordovician U–Pb zircon ages of about 480 Ma for trondhjemite of the Annieopsquotch Complex. We do not consider that these ages necessarily date the diabase dykes and gabbro of the Annieopsquotch Complex, which may be of Late Ordovician or Early Silurian age as documented by Whalen *et al.* (1987) for similar rocks in the Topsails terrane. This would be compatible with intrusion of the Lower Ordovician Glover group and Middle Ordovician Victoria Lake Group by diabase dykes and sills apparently related to the major mafic bodies. We draw attention to the work of Bédard (1986) who indicated that postorogenic mafic bodies of midocean ridge basaltic (MORB) chemistry occur in the Gaspé Peninsula. We feel that if major ophiolite allochthons were present, they must have passed over the southern Long Range uplands well above the present exposure level, as suggested by the high metamorphic grade suitable to the root of a collisional zone. Layers and lenses of highly deformed mafic to ultramafic rocks in the Central Gneiss terrane may mark thrust faults formed during a collisional event (van Berkel *et al.*, 1986; van Berkel, 1987a; Fox and van Berkel, *in press*). Thrust faults in the gneisses would be extremely difficult to detect due to extensive static recrystallization.

Major faults such as the Long Range, Victoria Lake and Little Grand Lake faults form impressive lineaments, but their role during collision remains obscure. Their present configuration results from late (Silurian–Carboniferous) brittle movement. Detailed examination of the ductile phase of movement of the Long Range and Victoria Lake faults suggests that dextral, sinistral and vertical motion all occurred. There is at present no evidence that the near vertical dip of these features decreases with depth. The drastic difference in metamorphic grade across these faults suggests that regardless of other motions, the Central Gneiss terrane is now uplifted with respect to its surroundings. The Annieopsquotch Complex may be separated from the Central Gneiss terrane by a major fault but we have been unable to find any major movement along this lineament. Minor structures associated with the Little Grand Lake Fault suggest that it could be a relatively late thrust, dipping northward at a moderate angle. As pointed out by Whalen and Currie (1983a,b), the lack of deformation in the Topsails terrane suggests that it is allochthonous and presumably thrust southward to truncate the surficial northeasterly trend of the southern Long Range.

ACKNOWLEDGMENTS

Field mapping assistance and stimulating discussions were provided by M.A.J. Piasecki in 1985, 1986 and 1987, by H.P. Johnston, J. Martin and S. Dawson in 1985, and by D. Machin and D. Fox in 1986 and 1987. Viking Helicopters of Pasadena supplied and moved the field parties. The Pasadena Forest Research Station of Environment Canada supplied base-camp space and logistical help. Kruger Incorporated and Abitibi-Price Limited gave permission to use woods roads. S. Colman-Sadd reviewed the manuscript.

REFERENCES

Bédard, J.H.
1986: Pre-Acadian magmatic suites of the southeastern Gaspé Peninsula. Geological Society of America Bulletin, Volume 97, pages 1177-1191.

Brown, P.A.
1976: Ophiolites in southwest Newfoundland. Nature, Volume 264, pages 712-715.

Chandler, F.W.
1982: Sedimentology of two middle Paleozoic terrestrial sequences, King George IV Lake area, Newfoundland and some comments on regional paleoclimate. *In* Current Research, Part A. Geological Survey of Canada, Paper 82-1A, pages 213-219.

Chandler, F.W. and Dunning, G.R.
1983: Fourfold significance of an early Silurian U−Pb zircon age from rhyolite in redbeds, southwest Newfoundland, NTS 12A/4. *In* Current Research, Part B. Geological Survey of Canada, Paper 83-1B, pages 419-421.

Currie, K.L.
1986: Harrys River (12B/9E) and part of Little Grand Lake (12A/12) map areas, southern Long Range, Newfoundland. Geological map (scale 1:50,000) with descriptive notes. Geological Survey of Canada, Open File Report 1406.

1987: A preliminary account of the geology of the Harrys River map area, southern Long Range of Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 653-662.

Dunning, G.R.
1984: The geology, geochemistry, geochronology and regional setting of the Annieopsquotch Complex and related rocks of southwest Newfoundland. Unpublished Ph.D. thesis, Memorial University, St. John's, Newfoundland, 403 pages.

1987: Geology of the Annieopsquotch Complex, southwest Newfoundland. Canadian Journal of Earth Sciences, Volume 24, pages 1162-1174.

Dunning, G.R. and Herd, R.K.
1980: The Annieopsquotch ophiolite complex, southwest Newfoundland, and its regional relationships. *In* Current Research, Part A. Geological Survey of Canada, Paper 80-1A, pages 227-234.

Dunning, G.R. and Krogh, T.E.
1985: Geochronology of ophiolites of the Newfoundland Appalachians. Canadian Journal of Earth Sciences, Volume 22, pages 1659-1670.

Dunning, G.R. and Chorlton, L.B.
1985: The Annieopsquotch ophiolite belt of southwest Newfoundland: Geology and tectonic significance. Geological Society of America Bulletin, Volume 96, pages 1466-1476.

Dunning, G.R., Kean, B.F., Thurlow, J.G. and Swinden, H.S.
1987: Geochronology of the Buchans, Roberts Arm and Victoria Lake groups and Mansfield Cove Complex, Newfoundland. Canadian Journal of Earth Sciences, Volume 24, pages 1175-1184.

Fox, D. and van Berkel, J.T.
In press: Mafic-ultramafic occurrences in metasedimentary rocks of southwestern Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 88-1A.

Herd, R.K. and Dunning, G.R.
1979: Geology of Puddle Pond map area, southwestern Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 79-1A, pages 305-310.

Hibbard, J.
1983a: Notes on the metamorphic rocks in the Corner Brook area (12A/13) and regional correlation of the Fleur de Lys Belt, western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 41-50.

1983b: Geology of the Island of Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 83-106.

Kean, B.F.
1983: Geology of the King George IV Lake map area (12A/4). Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-4, 67 pages.

Kennedy, D.P.
1981: Geology of the Corner Brook Lake area, western Newfoundland. Unpublished M.Sc. thesis, Memorial University, St. John's, Newfoundland, 370 pages.

Knapp, D.A.
1982: Ophiolite emplacement along the Baie Verte−Brompton Line at Glover Island, western Newfoundland. Unpublished Ph.D. thesis, Memorial University, St. John's, Newfoundland, 337 pages.

Knapp, D.A., Kennedy, D.P. and Martineau, Y.A.
1979: Stratigraphy, structure and regional correlation of rocks at Grand Lake, western Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 79-1A, pages 317-325.

Riley, G.C.
1957: Red Indian Lake (west half), Newfoundland. Geological Survey of Canada, Map 8-1957 (scale 1:250,000 with marginal notes).

van Berkel, J.T.
1987a: Geology of the Dashwoods Pond, St. Fintans and Main Gut map areas, southwest Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 399-408.

1987b: Geology of the Main Gut map area (12B/8), southwest Newfoundland. Geological map (scale 1:50,000) with descriptive notes. Geological Survey of Canada, Open File Report 1467.

1987c: Geology of the Dashwoods Pond (12B/1) and St. Fintans (12B/2) map areas, southwest Newfoundland. Geological map (scale 1:50,000) with descriptive notes. Geological Survey of Canada, Open File Report 1466.

van Berkel, J.T. and Currie, K.L.
1986: Geology of the southern Long Range, southwest Newfoundland (12B/1, 12B/8, 12B/9, 12A/5, 12A/2). Geological map (scale 1:50,000) with descriptive notes. Geological Survey of Canada, Open File Report 1328.

van Berkel, J.T., Johnston, H.P. and Currie, K.L.
1986: A preliminary report on the geology of the southern Long Range, southwest Newfoundland. *In* Current Research, Part B. Geological Survey of Canada, Paper 86-1B, pages 157-170.

Whalen, J.B. and Currie, K.L.
1983a: The Topsails igneous terrane of western Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 83-1A, pages 15-23.

1983b: Geology of the Topsails igneous terrane. Geological Survey of Canada, Open File Report 923 (1:100,000 map with marginal notes).

Whalen, J.B., Currie, K.L. and van Breemen, O.
1987: Episodic Ordovician-Silurian plutonism in the Topsails igneous terrane, western Newfoundland. Transactions of the Royal Society of Edinburgh, Volume 78, pages 17-28.

Williams, H.
1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 16, pages 792-807.

1985: Geology, Stephenville map area, Newfoundland. Geological Survey of Canada, Map 1579A (scale 1:100,000).

Current Research (1988) Newfoundland Department of Mines
Mineral Development Division, Report 88-1, pages 109-125

RELATIONSHIPS OF PHYLLITE, SCHIST AND GNEISS IN THE LA POILE BAY–ROTI BAY AREA (PARTS OF 11O/9 AND 11O/16), SOUTHWESTERN NEWFOUNDLAND

Brian H. O'Brien
Newfoundland Mapping Section

ABSTRACT

Two regional fault lineaments in southwestern Newfoundland, the Bay d'Est and Grand Bruit fault zones, control much of the tectonic development of the La Poile Bay–Roti Bay map area. Thrust bounded and stacked regionally from bottom to top are: 1) amphibolite-facies, metasedimentary and metavolcanic schist of the Ordovician Bay du Nord Group, 2) greenschist-facies, metavolcanic and metasedimentary phyllite of the Silurian La Poile Group and 3) amphibolite-facies, psammitic and amphibolitic gneiss of the Ordovician or earlier Cinq Cerf gneiss.

The Silurian Georges Brook Formation of the La Poile Group is locally separated into twenty members that comprise six major lithofacies typical of middle Paleozoic, felsic volcanic centres elsewhere in western Newfoundland. A protracted history of brittle-ductile, early Acadian faulting is indicated by inhomogeneous, polyphase deformation of Silurian strata and syntectonic emplacement of Silurian hypabyssal intrusions and sheet-like plutons. Nevertheless, pre-Silurian isotopic ages of postgneissification plutonic rocks near Grand Bruit and 'younger-over-older' thrust relationships near Bay d'Est suggest that Acadian contraction faults were situated on highly irregular surfaces of unconformity, syndepositional extension faults or exhumed thrust faults. These ancestral features are largely destroyed, but they may have originally separated autochthonous Silurian deposits from older metamorphic rocks represented by the Cinq Cerf gneiss and the Bay du Nord schist.

The present geometry of the metamorphic rocks in the thrust sheets resulted partly from early Acadian, step-shaped contraction faults, distinguished by bedding-parallel and foliation-parallel 'flats' and 'ramps', and partly from later Acadian, localized upright folds, possibly related to gravity-driven tectonomagmatic domes. The early thrusting produced large variations in regional strain, manifested itself in both recumbent and upright zones of simply folded and mylonitized rocks and was governed by a horizontal, compressive, maximum principal stress. The later doming caused a contrasting type of heterogeneous deformation, in which the original hanging walls of thrusts are displaced downdip on the steep flanks of domal structures. There, thrust-related mylonite zones undergo ductile extension faulting associated with diapiric uplift, tectonic unroofing of metamorphic rocks and contemporaneous emplacement of syntectonic sheet intrusions.

From the perspective of the regional geology, gold mineralization and related alteration are most likely produced by synmetamorphic, synplutonic fluids channelled through conduits in the brittle-ductile fault zones.

INTRODUCTION

The La Poile Bay–Roti Bay map area is situated between Port aux Basques and Burgeo on the southwest coast of insular Newfoundland (Figure 1). The map area is not serviced by roads and access is either by air or by sea.

During the 1987 field season, a geological mapping program was implemented that emphasized subdivision of the Silurian volcanic and sedimentary rocks of the Georges Brook Formation of the La Poile Group. This stratigraphic unit is host to the Hope Brook gold mine and to numerous other economic mineral occurrences. Other aims were to establish the structural relationships of the La Poile Group to the Ordovician Bay du Nord Group and the Ordovician or older Cinq Cerf gneiss, and to also determine the relationships that all three units have with granitoid and gabbroic rocks.

To the east, the La Poile Bay–Roti Bay map area joins the previously surveyed Grand Bruit–Cinq Cerf map area (Figure 1; O'Brien, 1987). As a result of work carried out in the past field season, the type area of the La Poile Group is now systematically mapped at 1:20,000 scale. Smaller-scale maps of the surrounding region were produced by Cooper (1954) and Chorlton (1978, 1980).

REGIONAL GEOLOGICAL SETTING

The most prominent feature of any simplified geological map of southwestern Newfoundland (e.g., Figure 2) is the

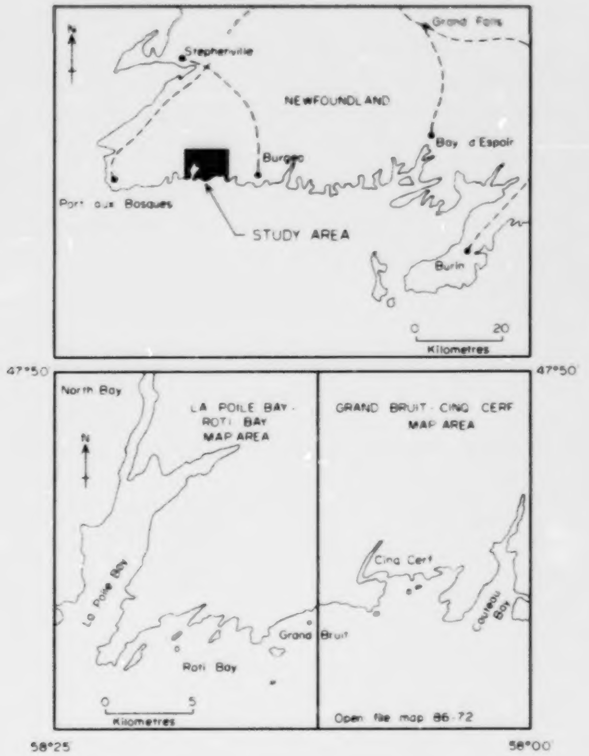


Figure 1. *Latitude, longitudes and relative position of the La Poile Bay–Roti Bay and the Grand Bruit–Cinq Cerf map areas in southwestern Newfoundland.*

presence of a series of major brittle–ductile faults, namely, the Long Range Fault (Hayes and Johnson, 1938), the Cape Ray Fault (Brown, 1973), the Bay d'Est Fault (Cooper, 1954) and the Grand Bruit Fault (Chorlton, 1978). These faults bound geological terranes, each of which contrast in metamorphic grade, structural style and stratigraphic framework. North of Port aux Basques, the Long Range Fault delimits the southeastern extent of relatively unmetamorphosed Paleozoic rocks. The terrane between the Long Range and Cape Ray faults is interpreted as relics of highly metamorphosed and dismembered ophiolites that are tectonically interleaved with Grenvillian basement in a belt of Precambrian and Paleozoic gneiss (Brown, 1976; Dunning and Chorlton, 1985; van Berkel, 1987). Farther southeast, the Cape Ray Fault locally coincides with the northwest boundary of a belt of Paleozoic gneiss and schist, probably formed from Ordovician sedimentary and volcanic rocks and typical of those in the Appalachian Gander Zone (Dunning *et al., in press;* O'Neill and Strong, 1988; Figure 2). In the study area, the Bay d'Est Fault juxtaposes Paleozoic phyllite against Paleozoic schist, whereas the Grand Bruit Fault separates gneiss of uncertain age from Paleozoic phyllite (Figure 2). The Lower Ordovician Bay du Nord Group (S. O'Brien *et al.*, 1986) is the local protolith of the Paleozoic schist terrane, whereas Paleozoic phyllite is confined to the outcrop area of the La Poile Group, recently dated by zircon geochronology as Late Silurian (Dunning *et al., in press).* The southeasternmost terrane of questionable Paleozoic or Precambrian gneiss is composed of amphibolitic and metasedimentary migmatite, which is locally undated and referred to as the Cinq Cerf gneiss. Regional faults having both horizontal and vertical displacements tectonically bound Bay du Nord schist, La Poile phyllite and Cinq Cerf gneiss (Figure 2).

GEOLOGY OF THE LA POILE BAY–ROTI BAY AREA

Introduction

The La Poile Bay–Roti Bay area is underlain by three groups of metasedimentary and metavolcanic rocks, and six map units of intrusive rocks (Figure 3). In order of decreasing abundance, the nonintrusive rocks are: 1) lower greenschist-facies, metavolcanic and metasedimentary rocks of the Silurian La Poile Group, 2) lower to upper amphibolite-facies, metasedimentary and metavolcanic rocks of the Ordovician Bay du Nord Group, and 3) upper-amphibolite facies, migmatitic, amphibolite gneiss, paragneiss and schist of the Ordovician or older Cinq Cerf gneiss. The six map units of intrusive rocks, listed from oldest to youngest, are: 1) the Cambro-Ordovician Roti Granite (Dunning *et al., in press),* 2) the Ordovician-Silurian(?) Western Head granite, 3) the Ernie Pond gabbro (probably Silurian), 4) the Silurian La Poile granite (Chorlton and Dallmeyer, 1986), 5) the Otter Point granite (probably Silurian) and 6) the Silurian Hawks Nest Pond porphyry (Chorlton and Dallmeyer, 1986).

Episodes of regional deformation that are common to all of these map units occurred during and after the juxtapositioning of the three groups of metasedimentary and metavolcanic rocks, as well as during and after the emplacement of the intrusive rocks. For at least part of the deformation history, progressive dynamothermal metamorphism of La Poile phyllite occurred simultaneously with retrogressive dynamothermal metamorphism of Bay du Nord schist and Cinq Cerf gneiss. Plutonism in the La Poile Bay–Roti Bay area occurred as phyllitic, schistose and gneissic host rocks were being metamorphosed at greenschist-facies conditions.

Metasedimentary and Metavolcanic Rocks

Cinq Cerf Gneiss. The Ordovician or older Cinq Cerf gneiss (CCG) outcrops as small enclaves in the Grand Bruit Fault Zone on the coast and offshore islands of the La Poile Bay–Roti Bay area (Figure 3). It is mostly composed of migmatitic, amphibolite gneiss and psammitic paragneiss, as well as abundant hornblendite and metagabbro.

Within the map area, metasedimentary and metavolcanic rocks of the Cinq Cerf gneiss are lithologically distinct from those of the Bay du Nord and La Poile groups. Furthermore, Bay du Nord and La Poile metasedimentary rocks locally contain large fragments of amphibolitized gabbro that were foliated prior to their incorporation as clasts. Assuming that the Cinq Cerf gneiss was the source of foliated metagabbro,

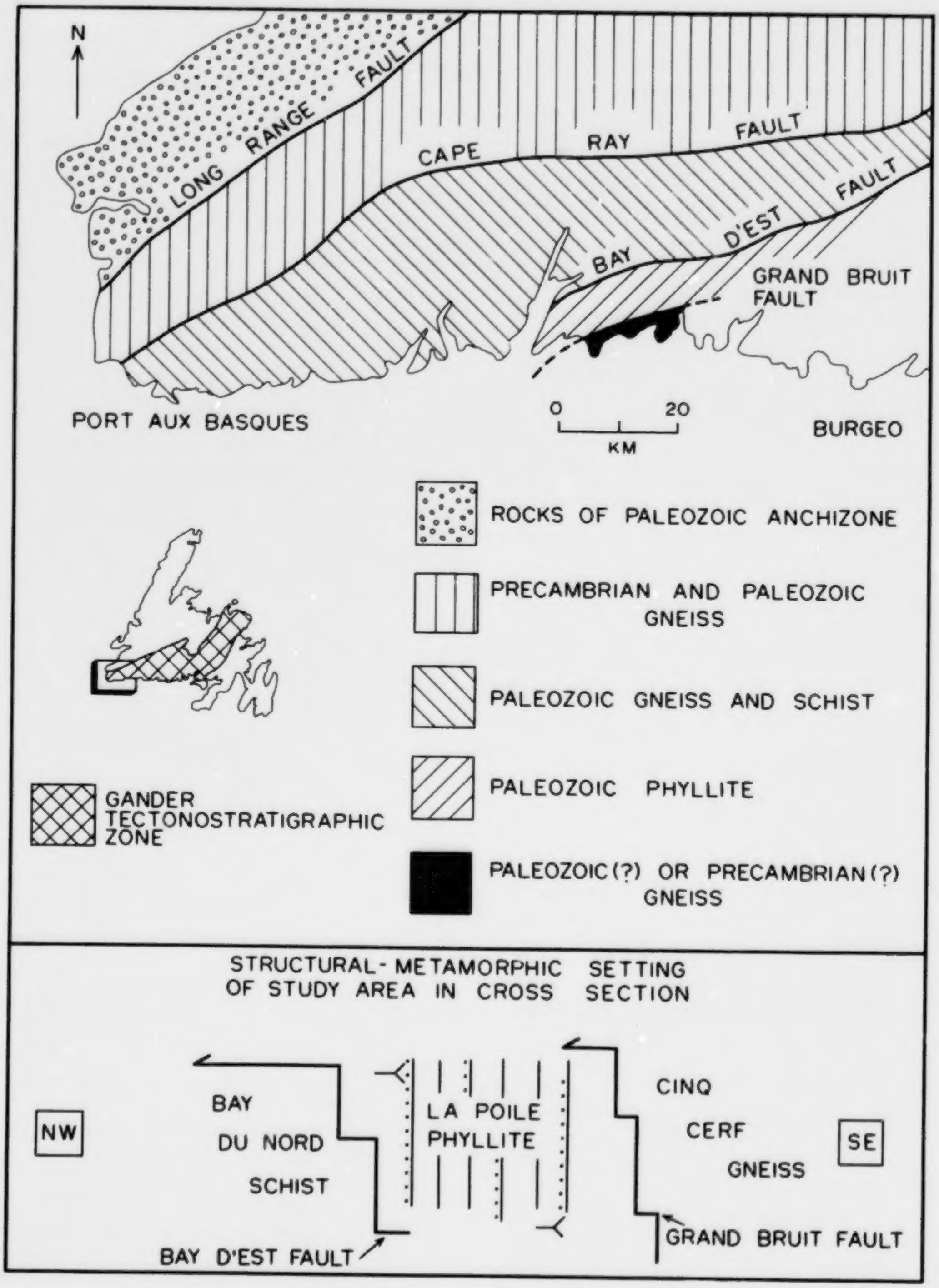

N
LONG RANGE FAULT
CAPE RAY FAULT
BAY D'EST FAULT
GRAND BRUIT FAULT
PORT AUX BASQUES
0
20
KM
BURGEO
ROCKS OF PALEOZOIC ANCHIZONE
PRECAMBRIAN AND PALEOZOIC GNEISS
PALEOZOIC GNEISS AND SCHIST
PALEOZOIC PHYLLITE
PALEOZOIC(?) OR PRECAMBRIAN(?) GNEISS
GANDER TECTONOSTRATIGRAPHIC ZONE
STRUCTURAL-METAMORPHIC SETTING OF STUDY AREA IN CROSS SECTION
NW
BAY DU NORD SCHIST
LA POILE PHYLLITE
CINQ CERF GNEISS
SE
BAY D'EST FAULT
GRAND BRUIT FAULT

Figure 2. *Simplified tectonic map of southwestern Newfoundland. Inset depicts the regional, structural and metamorphic setting of the study area. Arrows indicate stratigraphical facing directions.*

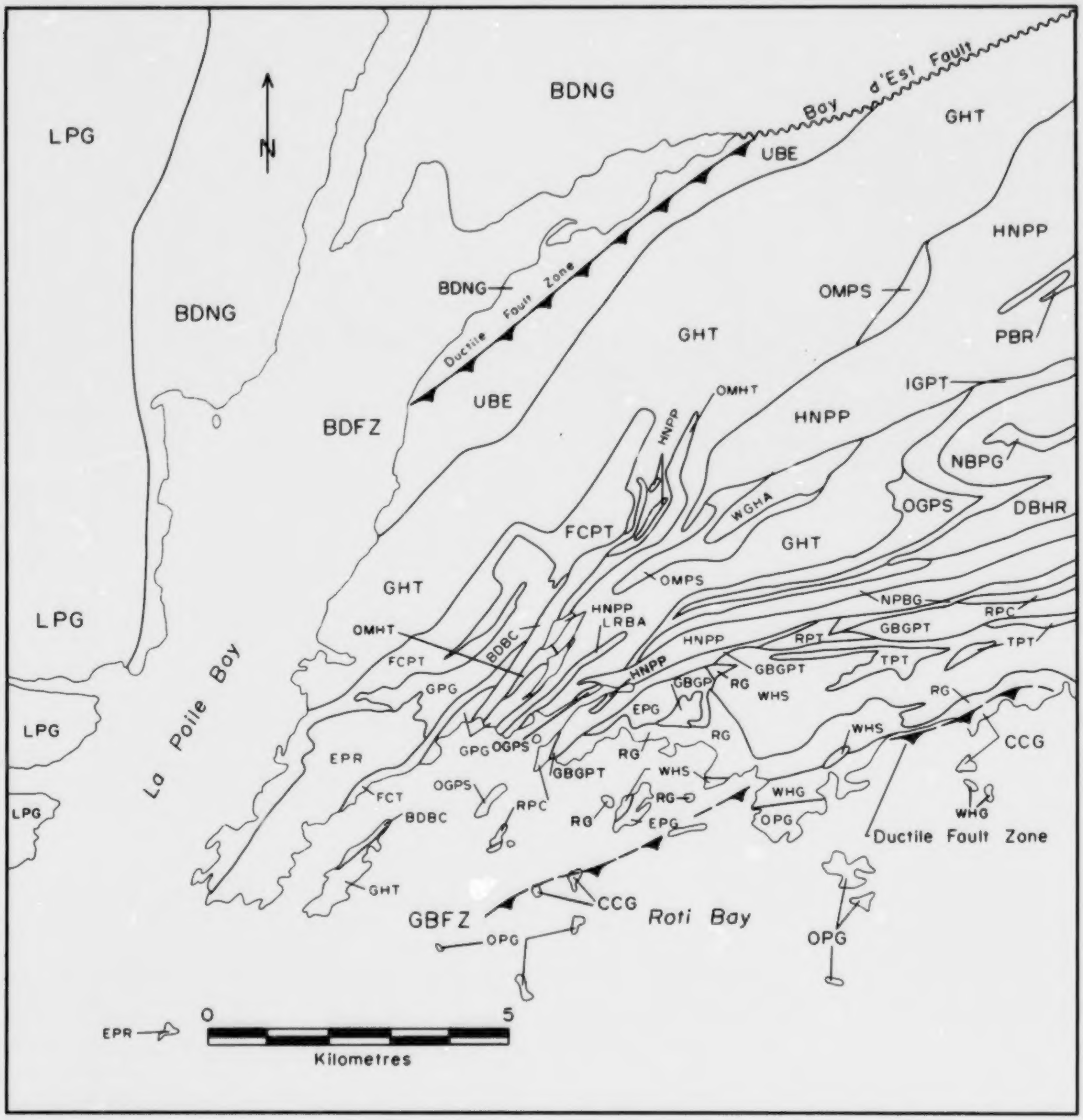

N
LPG
BDNG
Bay d'Est Fault
GHT
UBE
HNPP
BDNG
BDNG
Ductile Fault Zone
OMPS
GHT
PBR
IGPT
UBE
BDFZ
OMHT
HNPP
HNPP
NBPG
WGHA
OGPS
DBHR
FCPT
GHT
GHT
OMPS
LPG
OMHT
HNPP
LRBA
NPBG
RPC
BDBC
HNPP
RPT
GBGPT
TPT
FCPT
HNPP
GBGPT
TPT
La Poile Bay
GPG
GBGP
RG
WHS
RG
LPG
EPG
RG
WHS
CCG
GPG
OGPS
EPR
RG
GBGPT
WHS
RG
WHG
OGPS
FCT
RPC
RG
EPG
OPG
LPG
BDBC
WHG
Ductile Fault Zone
GHT
CCG
GBFZ
Roti Bay
OPG
OPG
EPR
0
5
Kilometres

Figure 3. *Geological map of the La Poile Bay–Roti Bay area, southwestern Newfoundland. Barbs on ductile faults indicate the regional dip direction of the Bay d'Est Fault Zone (BDFZ) and the Grand Bruit Fault Zone (GBFZ). See legend for explanation of other abbreviations.*

these observations might suggest that it is the oldest rock in the region. Along strike, however, east of the map area in the Grey River enclave, amphibolitic gneiss, paragneiss and orthogneiss similar to the Cinq Cerf gneiss are stated to comprise part of the Bay du Nord Group (Blackwood, 1985). If this inference is correct, then the age of migmatization of the Grey River gneiss is post-Early Ordovician and probably Silurian like the Port aux Basques gneiss to the west and the Little Passage Gneiss farther east (Dunning *et al.*, *in press*). Although the Cinq Cerf gneiss has been strongly deformed, metamorphosed and intruded by granitoids during the Acadian Orogeny, it was probably already gneissic prior to being thrust over the La Poile Group, and is accordingly designated as Ordovician or earlier in age.

Bay du Nord Group. In the La Poile Bay–Roti Bay area, the Ordovician Bay du Nord Group (BDNG) comprises metasedimentary and less common metavolcanic rocks that

LEGEND

SILURIAN

La Poile Group

DBHR	PBR	GBGPT	IGPT
WGHA	OMHT	FCT	FCPT
RPT	NPBG	GPS	WHS
OGPS	OMPS	BDBC	TPT
EPR	LRBA	GHT	RPC

Georges Brook Formation: metavolcanic and metasedimentary phyllite; descriptions of these members are shown in Figure 4

UBE	Georges Brook Formation: unseparated; mostly lithofacies B and E

Plutonic Rocks

HNPP	Hawks Nest Pond porphyry: biotite, quartz–feldspar porphyry
OPG	Otter Point granite: biotite, potassium feldspar-megacrystic granite
LPG	La Poile granite: biotite, potassium feldspar-megacrystic granite
EPG	Ernie Pond gabbro: hornblende-bearing gabbro and diorite; minor pyroxenite
WHG	Western Head granite: biotite–hornblende granodiorite
RG	Roti Granite: blue-quartz-bearing tonalite and granite

ORDOVICIAN

Bay du Nord Group

BDNG	unseparated metavolcanic and metasedimentary schist

ORDOVICIAN OR OLDER

Cinq Cerf gneiss

CCG	paragneiss and schist; amphibolite gneiss

are undifferentiated in Figure 3. Metasedimentary and metavolcanic formations of the Bay du Nord Group in the Grand Bruit–Cinq Cerf area illustrate complex map patterns (Cooper, 1954; Chorlton, 1978, 1980) that are produced by the interference of early recumbent and later upright folds (O'Brien, 1987). In the La Poile Bay–Roti Bay map area, however, Bay du Nord Group schist generally dips steeply toward the southeast, except locally near the Bay d'Est Fault Zone, where it dips gently to the southeast beneath the La Poile Group. Despite amphibolite-facies metamorphism, sedimentary and volcanic strata in the Bay du Nord Group are generally dissimilar to those in the structurally overlying La Poile Group. Although the regional younging direction of the Bay du Nord Group is unknown, bed tops at several localities face northwest (away from the younger La Poile Group) and graded metasedimentary rocks face structurally downward on a steeply dipping foliation.

La Poile Group. The stratigraphical thickness of the generally steeply dipping, northwest-younging, Silurian La Poile Group is estimated to be in the order of five kilometres. Chorlton (1978) grouped all the volcanic and sedimentary strata of the La Poile Group in the Georges Brook Formation. In the La Poile Bay–Roti Bay area, the Georges Brook Formation comprises twenty members, which are shown at 1:100,000 scale in Figure 3. Including the adjacent Grand Bruit–Cinq Cerf area, the Georges Brook Formation is divisible into twenty-four members within its type area. Informal names and lithological field descriptions of each unit are shown in Figure 4, along with the relative stratigraphical position of each member. Siliciclastic rocks dominate in the lower part, lava and epiclastic rocks in the middle part, and crystal tuff in the upper part of the Georges Brook Formation. Lithic tuff and agglomerate occur throughout all parts of the succession.

From Figures 3 and 4 it is evident that most members are discontinuous along their strike and that only the Whittle Hill sandstone (WHS), at the exposed base of the group, and the Gallyboy Harbour tuff (GHT), in the upper part of the group, were originally extensive enough to presently outcrop throughout and beyond the boundaries of the map area.

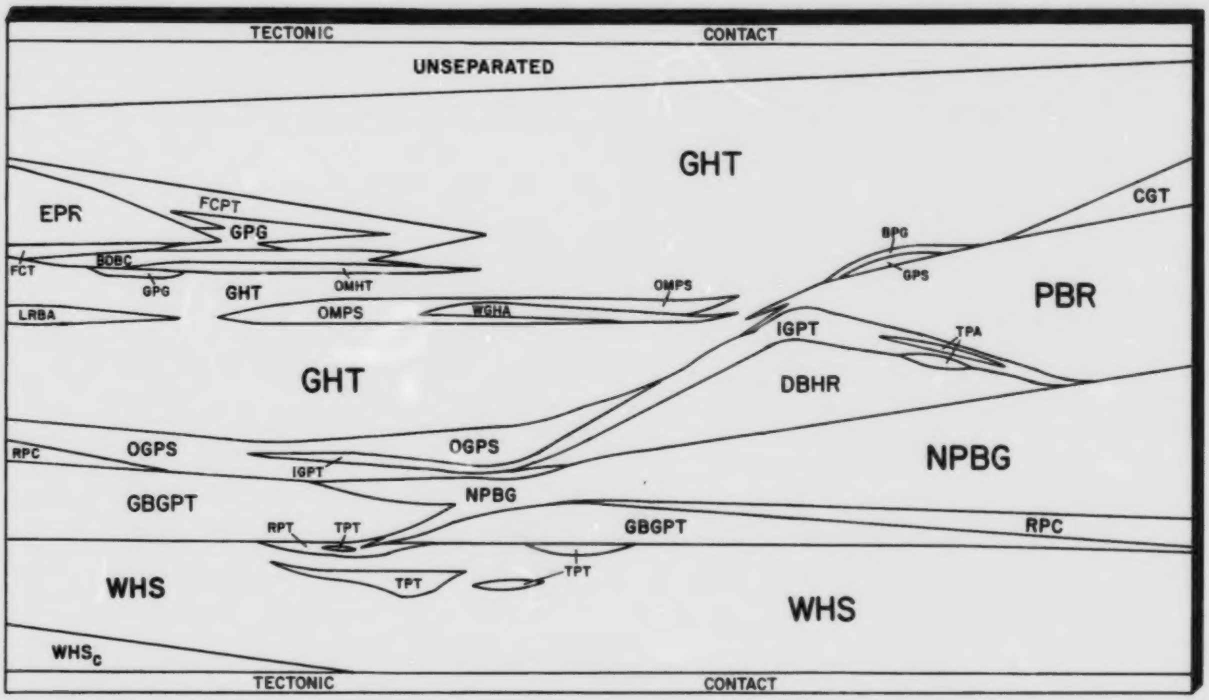


Figure 4. *Diagram illustrating the stratigraphical relationships of the twenty-four members of the Georges Brook Formation of the La Poile Group in its type area. Note the relative configuration of members in the La Poile Bay–Roti Bay area and their categorization into six major lithofacies. Note also that this pretectonic reconstruction is not a balanced cross-section and that the shapes of members are approximate or schematic. Lithofacies in accompanying legend are not in stratigraphical order.*

Members of the Georges Brook Formation probably terminate by stratigraphical pinch-out, since facies changes are commonly associated with the resulting wedges and splits. Primary variations in the original form of the members possibly controlled the shape and location of superimposed tectonic folds, e.g., the effect of the Eastern Point rhyolite (EPR). However, map unit terminations bear no set relation to fold geometry, as is exemplified in Figure 3, by the termination of the Inside Gull Pond tuff (IGPT) within the Outside Gull Pond slate (OGPS), or the pinch out of the Outside Gull Pond slate (OGPS) between the Withy Gulch Hill agglomerate (WGHA) and the Inside Gull Pond tuff (IGPT). For the most part, the wavelength and amplitude of the open to close, regional folds are an order of magnitude larger than the depositional strike length and primary thickness of the members. As a result, fold repetition of the Georges Brook Formation is not regionally significant. Nevertheless, due to the effect of primary pinch-out and map unit splitting, northwest-younging volcanosedimentary successions are internally variable and differ in makeup in parallel cross-sections.

Where any one particular member wedges out or is interdigitated with bordering map units, nearby members stratigraphically lower or higher in the succession commonly do likewise (Figure 4). Thus, local facies boundaries separating, for instance, volcanic and sedimentary deposits, persisted in one place for periods of time but then migrated laterally. This is consistent with eruptive centres changing location as deposits accumulated. The relative positions and wedged shapes of the Phillips Brook rhyolite (PBR), Dinner Box Hill rhyolite (DBHR) and Eastern Point rhyolite (EPR) may lend credence to this suggestion (Figures 3 and 4).

In this paper, the term lithofacies is used in the broadest definition of the word. Regionally mappable units comprise distinctive members composed of a plethora of individual rock types. Most members of the Georges Brook Formation can be ascribed to one of six major lithofacies that commonly recur throughout the succession (Figure 4). They are: (A) felsic lava flow, (B) felsic lithic tuff, (C) felsic crystal tuff, (D) epiclastic sediment, (E) quartz-rich clastic sediment and (F) mafic lithic tuff. A rare bed of limestone is locally present between the Guiders Pond grit (GPG) and the Gallyboy Harbour tuff (GHT).

In general, felsic volcanic rocks make up the greatest part of the Georges Brook Formation. In the La Poile Bay–Roti Bay area, volcaniclastic deposits are more voluminous than lava flows. Of the sedimentary rocks, epiclastic grit and wacke are spatially associated with rhyolite lava, whereas quartz-rich sandstone and argillite commonly occur with lithic tuff and felsic agglomerate. The middle part of the Georges Brook Formation contains most of the complexly interfingered lava,

LEGEND (Figure 4)

LITHOFACIES (A) : LAVA FLOW

Eastern Point Rhyolite	EPR	*massive, pink, aphanitic lava; locally welded*
Dinner Box Hill Rhyolite	DBHR	*flow-banded and massive, pink, locally phenocrystic lava; rare rhyolite breccia*
Phillips Brook Rhyolite	PBR	*massive and finely laminated, cream and pink lava; breccia composed of flow-banded rhyolite*

LITHOFACIES (B) : FELSIC LITHIC TUFF

Grand Bruit Gull Pond Tuff	GBGPT	*fine grained, light green, lithic tuff; red and purple lithic tuff and slate; quartz-pebble conglomerate*
Inside Gull Pond Tuff	IGPT	*fine grained, buff-weathered, lithic tuff; local breccia composed of pink rhyolite fragments; welded lithic–crystal tuff*
Little Roti Bay Agglomerate	LRBA	*crudely stratified, coarse agglomerate and breccia containing polymictic volcanic blocks; purple lithic tuff*
Withy Gulch Hill Agglomerate	WGHA	*agglomerate and breccia composed of massive, flow-banded and flow-folded rhyolite; minor pink and cream rhyolite*
Old Man Hill Tuff	OMHT	*buff-weathered, fine grained, lithic tuff composed of pink rhyolite fragments*
French Cove Tuff	FCT	*well-stratified, lithic tuff and breccia containing sedimentary and volcanic fragments; minor lithic–crystal tuff*
Cross Gulch Tuff	CGT	*lithic tuff composed of a variety of volcanic fragments*
Flint Cliff Pond Tuff	FCPT	*buff-weathered lithic tuff; coarse agglomerate composed of massive, pink rhyolite blocks; minor siliciclastic beds and rare lava flows*

LITHOFACIES (C) : CRYSTAL TUFF

Gallyboy Harbour Tuff	GHT	*pink, medium and coarse, locally layered and stratified, quartz–feldspar crystal tuff; rare blocks of volcanic and sedimentary rocks*
Round Pond Tuff	RPT	*pink, quartz (± feldspar) crystal tuff*

LITHOFACIES (D) : EPICLASTIC SEDIMENT

Northwest Pond Brook Grit	NPBG	*poorly sorted, grey-brown, massive and stratified, locally graded and crossbedded, quartz-feldspar grit and tuffaceous wacke; rip-up clasts and large blocks of laminated argillite; clasts of metamorphic and plutonic rocks*
Guiders Pond Grit	GPG	*poorly sorted, grey-brown, locally stratified, quartz-feldspar grit and tuffaceous wacke; minor boulder conglomerate and olistostrome; rare slate*
Butterfly Pond Grit	BPG	*poorly sorted, grey-brown, quartz–feldspar grit and tuffaceous wacke; grey slate*

LITHOFACIES (E) : SILICICLASTIC SEDIMENT

Whittle Hill Sandstone	WHS	*well-bedded, buff-weathered, quartz-rich sandstone; green and grey, laminated argillite; grey slate*
	WHS_C	*conglomerate subfacies of the Whittle Hill Sandstone; quartz-cobble conglomerate; polymictic cobble conglomerate*
Roti Point Conglomerate	RPC	*thick-bedded, polymictic, boulder and cobble conglomerate interstratified with thin-bedded sandstone; local and exotic clasts of volcanic, sedimentary, hypabyssal, plutonic and metamorphic rocks*
Outside Gull Pond Slate	OGPS	*grey slate and laminated argillite; rare thin-bedded sandstone*
Twin Pond Argillite	TPA	*laminated argillite; minor cobble and boulder, polymictic conglomerate; rare sandstone*
Georges Pond Slate	GPS	*grey slate and laminated argillite*
Old Man Pond Slate	OMPS	*grey slate and laminated argillite; minor thin-bedded sandstone and lithic tuff*
Black Duck Brook Conglomerate	BDBC	*polymictic, cobble and boulder conglomerate; siliciclastic sandstone interbedded with laminated argillite; minor grey slate*

LITHOFACIES (F) : MAFIC LITHIC TUFF

Third Pond Tuff	TPT	*green lithic tuff; minor green agglomerate; rare beds of laminated argillite*

lithic tuff and epiclastic sediment (e.g., Eastern Point rhyolite–Flint Cliff Pond tuff–Guiders Pond grit or Dinner Box Hill rhyolite–Inside Gull Pond tuff–Northwest Brook Pond grit). These strata were laid down on an extensive floor of mature, continentally derived, quartz-rich sediment (Whittle Hill sandstone) and were capped by a notably thick, homogeneous and laterally continuous deposit of quartz–feldspar crystal tuff (Gallyboy Harbour tuff). Mafic extrusive rocks, found only in the Third Pond tuff (TPT), are volumetrically insignificant, but they represent the earliest volcanic eruption in the La Poile depocentre.

Syntectonic Intrusive Rocks

Roti Granite. In the map area, the Roti Granite (RG) contains medium grained, blue-quartz-bearing tonalite west of Roti Bay and fine grained, biotite granite east of the bay. Mafic dyke swarms are present in the tonalite and the granite. The relationship between the two bodies is presently unknown but inherited Proterozoic zircons from the tonalite also yield latest Cambrian or earliest Ordovician ages (Dunning *et al., in press).*

Where the boundary of the Roti Granite locally trends northwest, the intrusion transects northeast-trending, gently to steeply plunging, megascopic folds in the Whittle Hill sandstone, which are outlined in part by the contact with the overlying Third Pond tuff. Later, larger-scale, vertically plunging folds, however, are defined by the trace of the intrusive contacts of the granite and the tonalite with the White Hill sandstone (Figure 3). Thus, the Roti Granite was emplaced and locally foliated during the folding of rocks presently included in the Georges Brook Formation.

On the offshore islands (Figure 3), the Roti Granite intrudes rocks as stratigraphically high in the Georges Brook Formation as the Grand Bruit Gull Pond tuff (GBGPT) and, perhaps, the Roti Point conglomerate (RPC). In this part of the map area, the Roti Granite is emplaced into a large, southwest-plunging, periclinal anticline along its northeast-trending, subvertical, fold axial surface (following O'Brien, 1987). In places, the intrusion cuts through the anticline, cored by the Whittle Hill sandstone, and comes in direct intrusive contact with the overlying Grand Bruit Gull Pond tuff in the fold hinge zone. At several localities, the Roti Granite and Silurian mafic dykes within it are themselves deformed by vertically plunging folds or are sheared in vertical mylonite zones.

Hypotheses to reconcile the observed field relationships with the Cambro-Ordovician age of the Roti Granite and the Silurian age of the Georges Brook Formation are discussed in a following section on pre-Silurian basement in the map area.

Western Head Granite. In the La Poile Bay–Roti Bay map area, the Western Head granite (WHG) is limited to a small tract of ground near the eastern head of Roti Bay (Figure 3). An Ordovician or Silurian crystallization age is likely, although absolute dates are unavailable. Cooper (1954) originally separated what is here termed the Western Head granite from other granitoids outcropping along the coast. On maps of the area, as well as in a genetic interpretation of the region, Chorlton (1978, 1980) subsequently grouped the Western Head granite with the Cinq Cerf gneiss in the Cinq Cerf complex (see Table 1, O'Brien, 1987). The Western Head granite is a name here proposed to identify the body of biotite–hornblende granodiorite originally mapped by Cooper and to re-exclude it from the older Cinq Cerf gneiss.

In the area mapped, Western Head granite crosscuts Cinq Cerf gneiss on various scales. Enclaves of well-banded gneiss occur in weakly foliated, biotite–hornblende granodiorite. Tectonic contacts of Western Head granite with Whittle Hill sandstone and Roti Granite are located in the Grand Bruit Fault Zone (Figure 3), where all units are highly sheared or mylonitized. In the Grand Bruit–Cinq Cerf area, however, an unfoliated part of the Western Head granite crosscuts penetrative foliation in an Early Cambrian phase (Dunning *et al., in press)* of the Roti Granite, which itself intrudes and includes Cinq Cerf gneiss (O'Brien, 1987). Nevertheless, in some localities, foliated Western Head granite is gradational with hornblende–biotite, leucotonalitic gneiss that comprises part of an amphibolitic agmatite in the Cinq Cerf gneiss. Therefore, it appears that intrusion of the Western Head granite is associated with Ordovician or Silurian agmatization of pre-Early Cambrian gneiss.

Ernie Pond Gabbro. The Ernie Pond gabbro (EPG) is best exposed in the La Poile Bay–Roti Bay area, where it consists of hornblende gabbro, diorite and minor pyroxenite. Together, they comprise an ellipsoidal body with a curved elongate tail on the mainland and a smaller, more circular body on the offshore islands (Figure 3). The Ernie Pond gabbro probably belongs to a suite of postophiolite, appinitic, Silurian gabbros in southwestern Newfoundland (van Berkel, 1987; Dunning *et al., in press).*

Part of the mainland body has the apparent shape of an incompletely exposed, subvertical ring dyke. Here, the gabbro–diorite body is largely unfoliated and intrudes variably plunging, open folds in the Grand Bruit Gull Pond tuff and the Whittle Hill sandstone. The margin of the Ernie Pond gabbro crosses the intrusive contact between the Roti Granite and the Grand Bruit Gull Pond tuff (Figure 3). In several localities, particularly within the tail of the intrusive body, the Ernie Pond gabbro carries a penetrative foliation.

Cordierite-bearing hornfels is well developed in the Whittle Hill sandstone where it is intruded by the Ernie Pond gabbro. Northeastward, discontinuous pods of hornfels within the Whittle Hill sandstone indicate the probable subcropping of a series of shallow-level bosses of Ernie Pond gabbro. Porphyroblasts of contact metamorphic origin overgrow an upright foliation but are themselves distorted and locally aligned.

A close spatial relationship exists between the bodies of Ernie Pond gabbro and the mafic dykes previously mentioned in this area and the Grand Bruit–Cinq Cerf map area

(O'Brien, 1987). On the Roti Bay islands, apophyses of Ernie Pond gabbro are chilled against Roti Granite, and gabbro apophyses and granite septae are folded together. The folded Ernie Pond gabbro–Roti Granite intrusive contact is crosscut by foliated mafic dykes. They occupy the vertical axial surfaces of folds of the intrusive contact, yet apparently emanate from the Ernie Pond gabbro. Thus, mafic dyke swarms and gabbro bosses were intruded and deformed during the folding of the Roti Granite, the Whittle Hill sandstone and the Grand Bruit Gull Pond tuff, presumably in the Acadian Orogeny.

Otter Point Granite. The Otter Point granite (OPG) is a variably deformed, biotite, potassium feldspar-megacrystic granite that underlies a small part of the coastline and the most seaward of the Roti Bay islands (Figure 3). It intrudes the Western Head granite and locally crosscuts the gneissosity in the Cinq Cerf gneiss. East of the map area, the Otter Point granite is intruded posttectonically by the Lower Devonian Chetwynd Granite (Chorlton and Dallmeyer, 1986). The age of crystallization and intrusion of the Otter Point granite is assumed to be Silurian.

The Otter Point granite is host to mafic dykes like those seen in most of the older map units, although the dykes form swarms near their intrusive contact with the Western Head granite. In the map area, unfoliated mafic dykes crosscut a penetrative foliation in the Otter Point granite. However, in the Grand Bruit–Cinq Cerf area, pegmatitic and aplitic phases of the Otter Point granite intruded the main megacrystic phase, the mafic dykes and the Western Head granite at the time these host rocks were being folded and foliated. Intrusion and deformation of the Otter Point granite overlapped the intrusion and deformation of the mafic dyke swarms in the Grand Bruit Fault Zone.

La Poile Granite. The La Poile granite (LPG) is a variably deformed, biotite, potassium feldspar-megacrystic granite that trends northerly and dips subvertically in the La Poile Bay–Roti Bay area (Figure 3). Cooper (1954) believed that it extended offshore and was probably contiguous with the northeast-trending Otter Point granite. In the map area, however, the La Poile granite is only seen in contact with the Bay du Nord Group.

The La Poile granite intrudes and discordantly truncates Bay du Nord schist striking northeast and dipping steeply southeast. Fine grained apophyses of leucogranite, grading from unfoliated or weakly foliated parts of the La Poile granite, crosscut host metasedimentary rocks containing subvertical, downward-facing, folds and foliations. However, in these same exposures, leucogranite apophyses are openly folded by upright folds, which developed on a larger scale and at a slightly later time than those affecting the schists. This implies that the La Poile granite was emplaced during the late upright folding of the Bay du Nord Group.

Hawks Nest Pond Porphyry. One major and several satellite bodies of Hawks Nest Pond porphyry (HNPP) occur in the La Poile Bay–Roti Bay area (Figure 3). Biotite-bearing, quartz–feldspar porphyry is the dominant rock type, although different textural varieties are found in most of these bodies. Distinctive green feldspars are saussuritized; secondary pyrite, white mica, and iron carbonate are common where the porphyry is highly altered. Chorlton and Dallmeyer (1986) reported a Silurian age for the crystallization of the Hawks Nest Pond porphyry.

All bodies of Hawks Nest Pond porphyry trend northeast, dip subvertically and intrude the Georges Brook Formation (Figure 3). Those emplaced into the limbs of regional folds (e.g., the body locally separating the Grand Bruit Gull Pond tuff (GBGPT) and the Northwest Pond Brook grit (NPBG) are sills, whereas those emplaced through the hinge zones of regional folds (e.g., the large body intruding the Inside Gull Pond tuff (IGPT), the Gallyboy Harbour tuff (GHT), the Old Man Pond slate (OMPS) and the Withy Gulch Hill agglomerate (WGHA) are dykes. The Hawks Nest Pond porphyry transects map-scale folds in the Georges Brook Formation, has xenoliths showing disoriented intersections of cleavage and bedding, and is itself locally folded and foliated. In the map area, intrusion of the Hawks Nest Pond porphyry occurred during upright Acadian folding of the La Poile Group.

Intrusive Felsites. Folded and locally foliated intrusive bodies of aphanitic rhyolite or rhyolite porphyry occur in the Grand Bruit Fault Zone and areas to the northwest. These felsites are not mappable at the 1:100,000 scale of Figure 3 but some can be accurately shown on larger-scale maps. The largest body intrudes the Grand Bruit Gull Pond tuff and the Roti Point conglomerate; smaller dykes intrude the Whittle Hill sandstone and the Roti Granite. The intrusive felsites partially overlap the emplacement of the mafic dyke swarms.

PROBLEM OF THE PRE-SILURIAN BASEMENT

Because the Grand Bruit Fault Zone has been invaded by copious amounts of magma (O'Brien, 1987), migmatite of the Cinq Cerf gneiss, schist of the Bay du Nord Group and phyllite of the La Poile Group are never seen in direct contact with each other. Greenschist-facies deformation common to all rock types is associated with the syntectonic emplacement of Silurian sheet intrusions. However, magmas of Cambrian, Ordovician and Silurian age (Dunning *et al.*, *in press)* intruded and included gneiss, schist and phyllite in close proximity to each other in the Grand Bruit Fault Zone. These data, and the evidence of locally derived granitoid clasts with a preincorporation foliation in the Bay du Nord and La Poile groups, imply that one or more of the following hypotheses are likely. First, some or all of the migmatitic rocks included in the Cinq Cerf gneiss are pre-Silurian (possibly Precambrian) and that they cannot have their protoliths in either the Bay du Nord Group or the La Poile Group. This is in direct contrast to suggestions made for the central part of the Hermitage Flexure (following S. O'Brien *et al.*, 1986). Second, some phyllitic rocks presently included in the basal part of the Georges Brook Formation are pre-Silurian and, therefore, should be excluded from the La Poile

Group and perhaps be reassigned to either the Bay du Nord Group or the Cinq Cerf gneiss (following Cooper, 1954). Third, some plutons yielding Early Cambrian and Late Cambrian–Early Ordovician zircon ages may have crystallized from magma at that time (Dunning *et al., in press*). However, this does not preclude reintrusion of the plutons into the Georges Brook Formation cover as the basement of pre-Silurian gneiss and schist was remobilized in the Acadian Orogeny. Finally, some intrusive map units may contain unseparated Silurian and Cambro-Ordovician plutons. As a result, they may locally display field relationships that apparently contradict those observed for the same intrusive unit in other map areas (S. O'Brien, personal communication, 1987) or that appear to be unreconcilable with absolute ages of minerals from other parts of the intrusive unit (O'Brien, 1987). At this stage of the research on the map area, it is difficult to evaluate the relative likelihood of any of these possibilities.

STRUCTURAL GEOLOGY

The structure of the Cinq Cerf gneiss, the Bay du Nord Group and the La Poile Group has been previously discussed by Chorlton (1978, 1980), Chorlton and Dallmeyer (1986) and O'Brien (1987). Major and minor structures similar to those described in the Grand Bruit–Cinq Cerf map area (O'Brien, 1987) extend into and occur throughout the La Poile Bay–Roti Bay map area.

An Overview

The major structural features of the metasedimentary and metavolcanic rocks, and the gabbroic to granitic intrusions to which they are host, are summarized in Figure 5. Amphibolite-facies schist and gneiss occur in flat-lying Bay du Nord Group and steeply inclined Cinq Cerf gneiss, respectively, southeast of the Grand Bruit Fault Zone. During amphibolite-facies deformation (D_{1a}), a schistose or gneissic foliation (S_{1a}) developed parallel to primary layering. This foliation is now concordant with the 'flat' and 'ramp' portion of the Grand Bruit thrust. Within the hanging wall sequence, the unexposed schist–gneiss contact (question mark in Figure 5) could be either a thrust parallel to the Grand Bruit structure or a gradational metamorphic boundary (following Blackwood, 1985). In the Bay du Nord Group northwest of the Bay d'Est Fault Zone, flat-lying and steeply inclined, bedding–parallel, S_{1a} schistosity is present beneath thrust-related, greenschist-facies mylonites (Figure 5). Post-D_{1a} structures in the Cinq Cerf gneiss and the Bay du Nord Group probably formed during greenschist-facies deformation of the La Poile Group, which by then intervened as a thrust sheet between the northwestern and southeastern belts of amphibolite-facies rocks (Figure 5).

Three superposed episodes of regional deformation (D_{1g}, D_{2g} and D_{3g}) accompanied chlorite-grade, dynamothermal metamorphism of the La Poile Group (O'Brien, 1987). Phyllitic cleavages and folds related to the D_{1g} and D_{2g} deformations are coaxial and locally coplanar; D_{3g} structures are invariably noncoaxial.

The regional S_{1g} slaty cleavage is axial planar to both gently plunging, upright periclinal folds and subrecumbent asymmetrical folds (Figure 5). Above and below the 'flats' of the major thrust faults, the openly folded, right-way-up, generally northwest-younging strata of the La Poile Group were inverted as the regional D_{1g} strain increased and minor F_{1g} subrecumbent folds and gently dipping S_{1g} mylonites developed. The transition from upright to recumbent structures produced Pyrennean-type, half-fans of cleavage and bedding on regional and local scales. Near the 'ramps' of the thrusts, vertical slaty cleavage is axial planar in tight, generally steeply plunging periclines, which are commonly seen on at least three orders of magnitude. With increasing D_{1g} strain, minor F_{1g} folds become isoclinal and neutral as fold axes rotate into the vertical extension direction of ramp-parallel belts of S_{1a} mylonite.

The regional S_{2g} crenulation cleavage is variably penetrative and, where well developed, is spatially associated with faults or intrusions. The invariably upright F_{2g} folds formed after the thrusts had acquired their 'stepped' shape and after the S_{1g} slaty cleavage was fanned into 'one-sided' flower structures. Therefore, near thrust 'flats', gently plunging F_{2g} folds coaxially overprint F_{1g} subrecumbent folds, and vertical S_{2g} cleavage crenulates gently dipping S_{1g} slaty cleavage. In contrast, near thrust 'ramps', vertically plunging F_{2g} and F_{1g} folds are coaxial, and upright S_{2g} and S_{1g} cleavages are coplanar. With increasing D_{2g} strain, concordant intrusions within the ramp-parallel, D_{1g} mylonite belts are themselves mylonitized. In the oldest intrusions, the D_{2g} extension direction accompanying protoclastic deformation is vertical. Assuming that the regionally consistent vergence of the F_{2g} folds is meaningful, the southeast side or original hanging walls of the thrusts were offset downward by ductile D_{2g} faulting (O'Brien, 1987). The youngest mylonitic intrusion in the Grand Bruit Fault Zone is affected by dextral strike-slip movements.

Sheet intrusions of variable size, texture, composition and age were emplaced along F_{1g}-fold axial surfaces and S_{1g} slaty cleavage and, as a result, the majority of intrusive bodies dip vertically rather than horizontally (Figure 5). F_{2g} folds of La Poile Group country rocks commonly deform the margins of post-F_{1g} intrusions. In vertical bodies, the primary steep foliation produced near the walls of the intrusions is parallel to the S_{2g} crenulation cleavage in the host rocks. In subhorizontal bodies, S_{2g} cleavage is subperpendicular to the wall of the intrusion and gently plunging, F_{2g} upright folds crenulate the concordant primary foliation. These structures are, however, coplanar with vertical offshoots emanating from the flat-lying sheets (Figure 5). Between faults and away from intrusions, D_{1g} structures are not affected by D_{2g} deformation.

The noncoaxial D_{3g} deformation produced F_{3g} cross-folds and locally developed S_{3g} crenulation cleavage. Such structures overprint a variety of D_{1a}, D_{1g} and D_{2g} features and are present in most map units. Steeply plunging F_{3g} minor folds are related to open, Z-shaped flexures of map units, and presumably result from strike-parallel shortening.

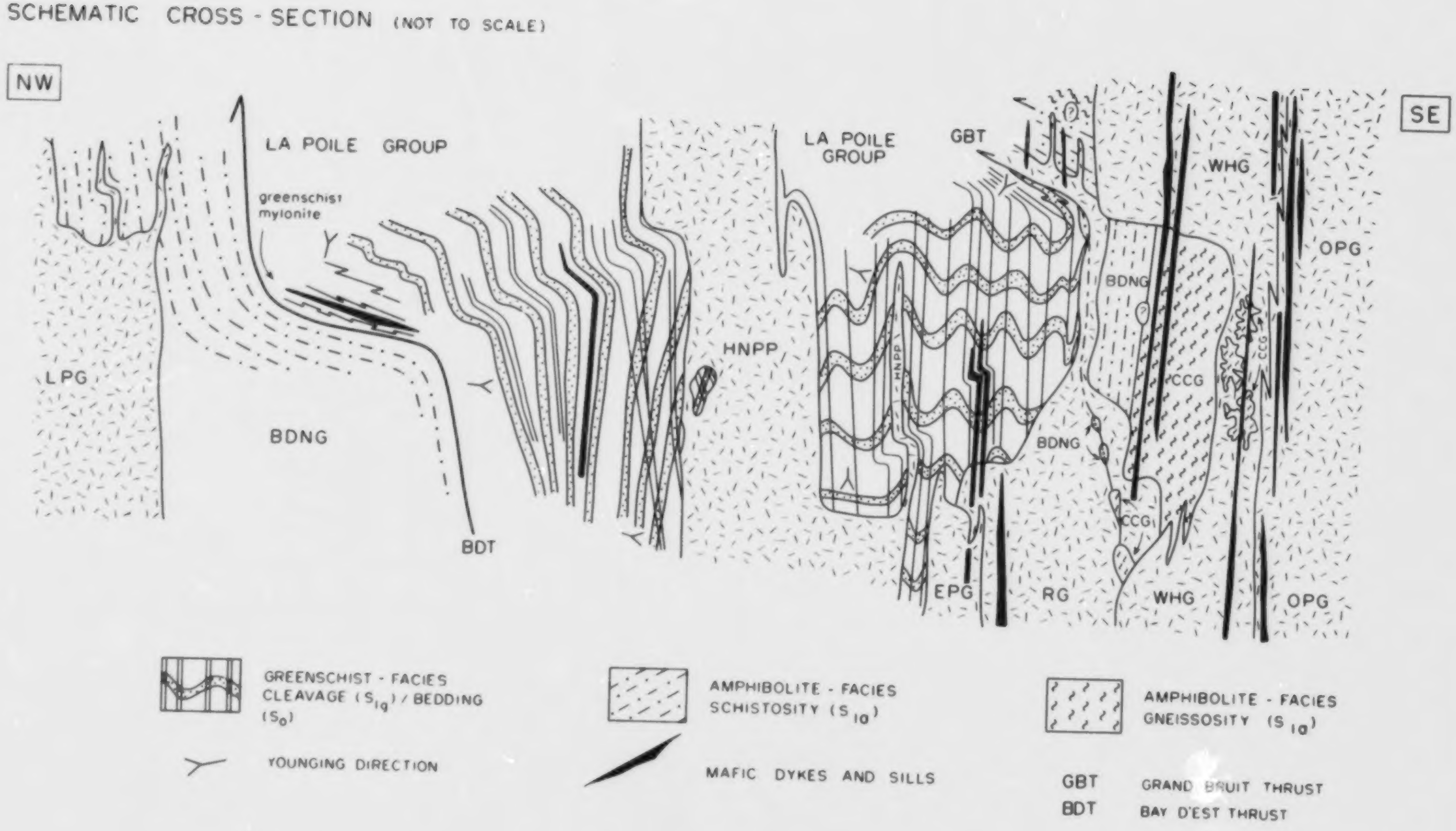

SCHEMATIC CROSS - SECTION (NOT TO SCALE)
NW
SE
LA POILE GROUP
greenschist mylonite
LPG
BDNG
BDT
HNPP
LA POILE GROUP
GBT
HNPP
BDNG
CCG
WHG
OPG
CCG
BDNG
CCG
EPG
RG
WHG
OPG
GREENSCHIST - FACIES CLEAVAGE (S1a) / BEDDING (S0)
YOUNGING DIRECTION
AMPHIBOLITE - FACIES SCHISTOSITY (S1a)
MAFIC DYKES AND SILLS
AMPHIBOLITE - FACIES GNEISSOSITY (S1a)
GBT GRAND BRUIT THRUST
BDT BAY D'EST THRUST

Figure 5. *Simplified, regional, vertical cross-section illustrating the structural, metamorphic and intrusive relationships (observed and inferred) of map units in the La Poile Bay–Roti Bay–Grand Bruit–Cinq Cerf area.*

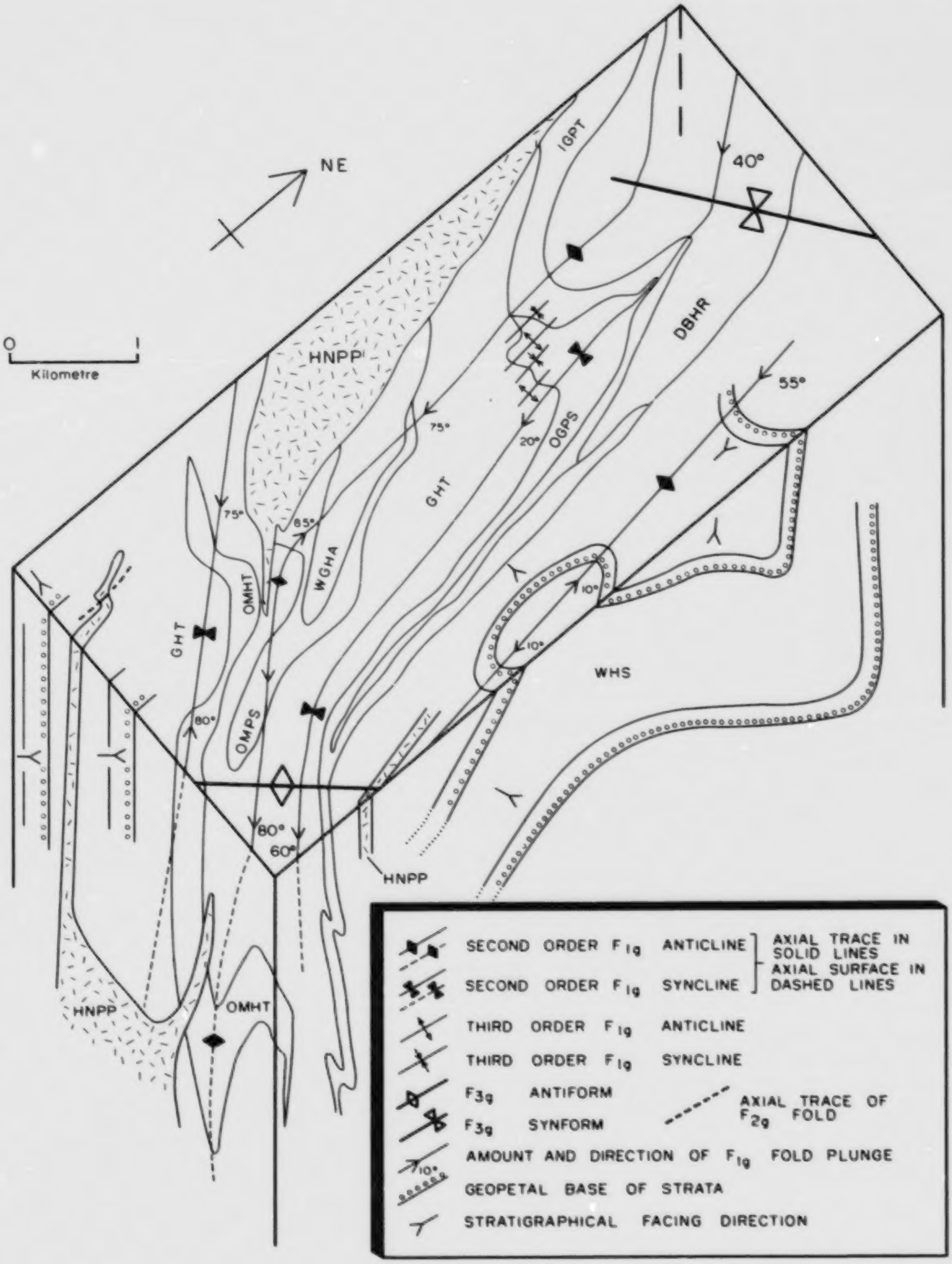

NE
0
1
Kilometre
IGPT
40°
DBHR
HNPP
55°
75°
20°
OGPS
GHT
75°
85°
WGHA
OMHT
10°
10°
GHT
WHS
80°
OMPS
80°
60°
HNPP
HNPP
OMHT
SECOND ORDER F1g ANTICLINE
SECOND ORDER F1g SYNCLINE
AXIAL TRACE IN SOLID LINES
AXIAL SURFACE IN DASHED LINES
THIRD ORDER F1g ANTICLINE
THIRD ORDER F1g SYNCLINE
F3g ANTIFORM
F3g SYNFORM
AXIAL TRACE OF F2g FOLD
10°
AMOUNT AND DIRECTION OF F1g FOLD PLUNGE
GEOPETAL BASE OF STRATA
STRATIGRAPHICAL FACING DIRECTION

Figure 6. *Block diagram illustrating the typical structure of the La Poile Group throughout most of the La Poile Bay–Roti Bay map area. Note the post-F_{1g}, pre-F_{2g} age of the intrusion and the relation of map unit terminations to the F_{1g} folds. See legend to Figure 3 for explanation of abbreviations.*

STRUCTURE OF THE MAP AREA

In the La Poile Bay–Roti Bay map area, the discontinuously exposed Cinq Cerf gneiss marks the trace of the Grand Bruit Fault Zone. Small, lenticular, partly digested enclaves of gneiss containing subvertical S_{1a} foliation occur in mylonitized parts of the Western Head and Otter Point granites. Tight to isoclinal, vertically plunging F_{2g} folds of foliated mafic dykes and S_{1a} gneissosity are commonly observed.

The Bay du Nord Group has been affected by the regional D_{1a}, D_{2g} and D_{3g} deformations in the La Poile Bay–Roti Bay area. Bedding-parallel S_{1a} schistosity and L_{1a} lineation dip and plunge steeply to the southeast and are overprinted by a variably penetrative, upright, locally downward-facing, S_{2g} crenulation cleavage. The S_{2g} foliation is axial to minor F_{2g} folds that illustrate vergence consistent with that of F_{2g} folds in the La Poile Group and Cinq Cerf gneiss. Regional F_{2g} fold vergence is toward a synform lying southeast of the map area (O'Brien, 1987). White micas of metamorphic origin grew syn- to post-kinematically with respect to the S_{2g} crenulation cleavage. In zones where the D_{2g} strain is large, grain-size reduction of the relatively coarse grained minerals of the S_{1a} schistosity accompanied S_{2g} foliation development. In D_{2g} mylonite zones porphyroclasts of coarse grained, polymineralic aggregates, representing relics of the climactic S_{1a} assemblage, sit in a fine grained, sericite–quartz matrix. West-northwest-trending F_{3g} minor folds and axial-planar, S_{3g} crenulation cleavage overprint northeast-trending S_{1a} and S_{2g} foliations.

In the La Poile Bay–Roti Bay area, excellent examples of superimposed D_{1g}, D_{2g} and D_{3g} structures are present in the Georges Brook Formation. The second-order F_{1g} folds depicted in Figure 6 are developed parasitically on the right-way-up, southeast limb of a first-order, regional fold called the La Poile Syncline (Cooper, 1954). The northwest limb of this fold is not found in the type area of the La Poile Group. Since it is unlikely that southeast-younging rocks are everywhere concealed within mylonites of the Bay d'Est Fault Zone (Figure 3), the La Poile Group is believed to be inverted where it overlies gently southeast-dipping schist of the Bay du Nord Group (Figures 5 and 6).

Away from the 'flats' of the northwest-directed D_{1g} thrusts, all members, intrusions and major structures in the northwest-facing Georges Brook Formation are generally steeply dipping. The structure typical of most of the La Poile Group is illustrated in Figure 6 as a block diagram representing an approximate volume of 55 cubic kilometres. Noteworthy are: 1) variably plunging, second- and third-order F_{1g} periclines that fold discontinuous, originally discoidal members, 2) the upright to steeply inclined, axial surfaces of the F_{1g}, F_{2g} and F_{3g} folds, 3) the coaxial relationship between F_{1g} and F_{2g} folds, 4) the post-F_{1g}, pre-F_{2g} intrusive age of the Hawks Nest Pond porphyry, and 5) the noncoaxial F_{3g} crossfolds and their relation to the Z-shaped flexures of map units and earlier folds.

RELATIONSHIP OF D_{1a} AND D_{1g} DEFORMATION

The regional cross-section illustrated in Figure 7 is a simplified representation of the relationship between the Ordovician Bay du Nord Group and the Silurian La Poile Group near the Bay d'Est Fault Zone. The amphibolite-facies D_{1a} and greenschist-facies D_{1g} episodes of regional deformation produced recumbent folds in regionally inverted successions, presently seen above and below the 'flats' of domed thrust faults. Episodes of D_{1a} and D_{1g} deformation predated sheet intrusion, upright folding and extension faulting, and greenschist-facies metamorphism during regional D_{2g} deformation. Although overprinting of S_{1a} gneissosity or schistosity by S_{2g} crenulation cleavage is associated with grain-size reduction and retrogression, S_{1a} and S_{1g} foliations are not observed in direct contact. Two possible relationships, however, are outlined below.

First, belts of thrust-related mylonite commonly separate map units of metavolcanic and metasedimentary rocks carrying either S_{1a} or S_{1g} foliation. Although the depositional ages of nonintrusive units may vary across thrusts, the Silurian or later metamorphic age of S_{1a} and S_{1g} foliation may be similar. Assuming that horizontal Acadian isograds were ductilely displaced by Acadian thrust faults, belts of mylonite should contain a series of concordant, very closely spaced, isograd surfaces. In the Grand Bruit Fault Zone, where upper-amphibolite-facies rocks are separated from lower-greenschist-facies rocks by as little as 10 m of mylonite, a notably steep, inverted, Acadian metamorphic gradient is required to produce parallel S_{1a} and S_{1g} foliations. The lack of evidence of heat transfer between low-grade and high-grade thrust sheets presumably implies that insufficient time was available to permit re-equilibriation prior to cooling. However, in the Bay d'Est Fault Zone, where 'cold' greenschist-facies rocks overthrust 'hot' amphibolite-facies rocks, such explanations are unlikely (Figure 7).

A second possible relationship is that the S_{1a} schistosity in the Bay du Nord Group and the S_{1a} gneissosity in the Cinq Cerf gneiss formed prior to the deposition of the Upper Silurian La Poile Group. The fact that pre-La Poile Group (S_{1a}) and post-La Poile Group (S_{1g}) foliations are parallel to each other on the 'flats' and 'ramps' of thrusts is simply a measure of the regional Acadian strain. Although agmatization of Cinq Cerf gneiss may have accompanied syntectonic intrusion of Upper Silurian granitoids, S_{1a} gneissosity may have developed prior to the Early Cambrian. In contrast, in the Bay du Nord Group, the age of S_{1a} schistosity is presumably post-Early Ordovician, pre-Late Silurian. In this explanation, the younger S_{1g} foliation would likely overprint the older S_{1a} foliation, and gneiss and schist would be retrogressed near thrust-related D_{1g} mylonites (Figure 7).

ALTERATION AND MINERALIZATION

Zones of silicic, pyritic or sericitic alteration are widespread in the La Poile Bay–Roti Bay area (Figure 8).

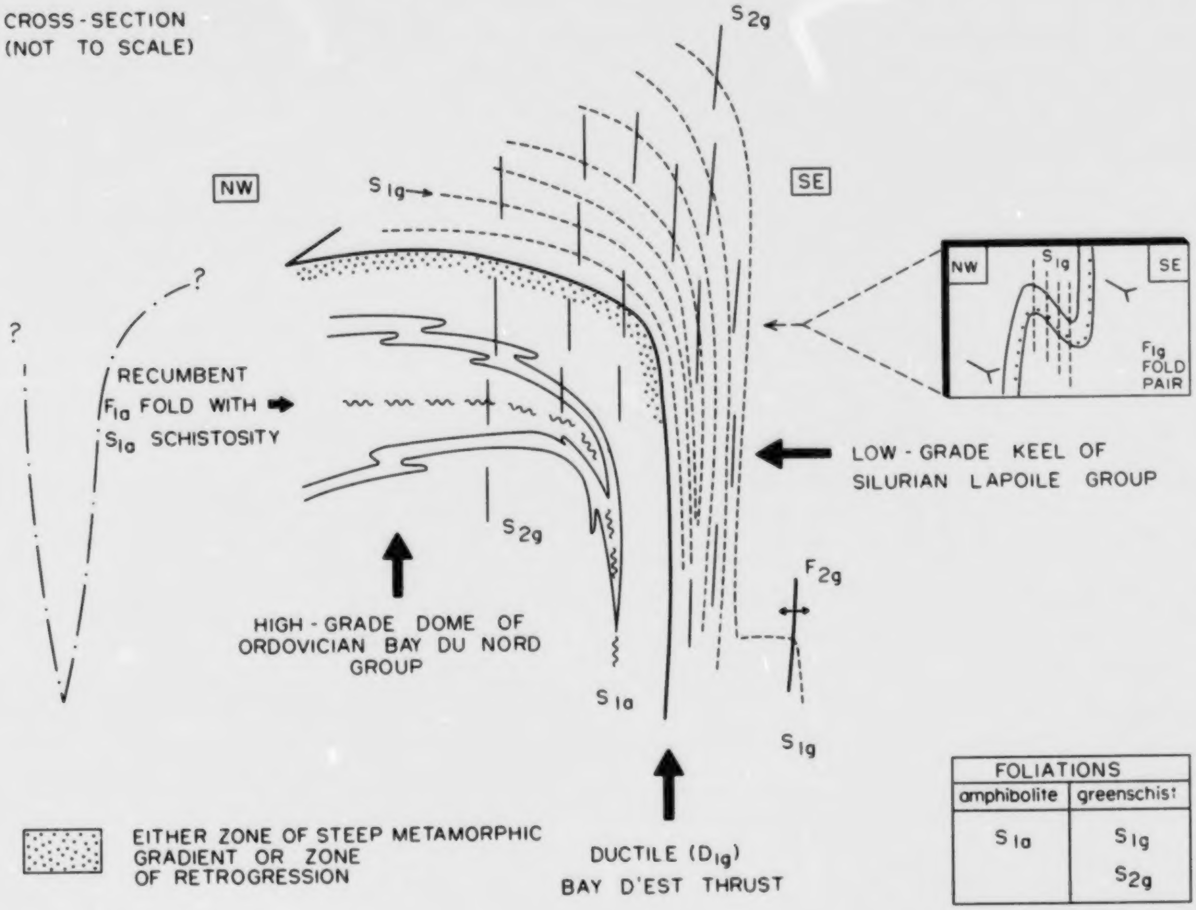

CROSS-SECTION
(NOT TO SCALE)
NW
SE
S_{1g}
S_{2g}
?
?
RECUMBENT
F_{1a} FOLD WITH
S_{1a} SCHISTOSITY
NW
SE
S_{1g}
F_{1g}
FOLD
PAIR
LOW-GRADE KEEL OF
SILURIAN LAPOILE GROUP
S_{2g}
F_{2g}
HIGH-GRADE DOME OF
ORDOVICIAN BAY DU NORD
GROUP
S_{1a}
S_{1g}
EITHER ZONE OF STEEP METAMORPHIC
GRADIENT OR ZONE
OF RETROGRESSION
DUCTILE (D_{1g})
BAY D'EST THRUST
FOLIATIONS
amphibolite
greenschist
S_{1a}
S_{1g}
S_{2g}

Figure 7. *Idealized, vertical, sketch-section showing the structural relationship between the Ordovician Bay du Nord Group and the Silurian La Poile Group. Applying models of Archean greenstone belts, this 'dome-keel' geometry may be caused by vertical gravitational forces (as opposed to horizontal compressional forces). Inset shows the vergence and facing directions of the F_{1g} folds in the La Poile Group. Note how these features contrast with those of the F_{2g} folds related to the Ordovician-cored dome.*

Alteration zones are located in the Georges Brook Formation, the Bay du Nord Group, the Hawks Nest Pond porphyry and the Roti Granite. Lake sediment geochemistry maps of southwestern Newfoundland show that the region southeast of the Bay d'Est Fault Zone is anomalously enriched in Sb, As, Pb, Se and Au (Davenport and Nolan, 1987; McConnell, 1987).

Within the Georges Brook Formation, discontinuous stratabound zones of alteration occur in the Whittle Hill sandstone, the Third Pond tuff, the Northwest Pond Brook grit, the Roti Point conglomerate, the Grand Bruit Gull Pond tuff, the Withy Gulch Hill agglomerate, the Gallyboy Harbour tuff, the Flint Cliff Pond tuff and unseparated rocks (UBE) at the top of the La Poile succession. Phyllosilicate- and sulphide-bearing alteration products in nonintrusive map units are commonly deformed indicating either a pretectonic or syntectonic origin. Any pretectonic alteration must be older than the alteration affecting the granitoids. If it is related to the accumulation of Upper Silurian volcanic rocks, then it is evident that stratabound alteration does not depend on stratigraphic position. Furthermore, a unique relationship does not exist between alteration horizons and particular members or broad lithofacies of the Georges Brook succession. Alternatively, if the alteration process accompanies syn-D_{2g} intrusion of granitic and gabbroic rocks, and synmetamorphic faulting of the Georges Brook Formation, then proximity to concordant sheet intrusions and/or major faults may be an important factor in locating gold mineralization (Figure 8).

SUMMARY AND CONCLUSIONS

In the La Poile Bay–Roti Bay area, metavolcanic and metasedimentary rocks of the Upper Silurian Georges Brook Formation of the La Poile Group are separable into twenty

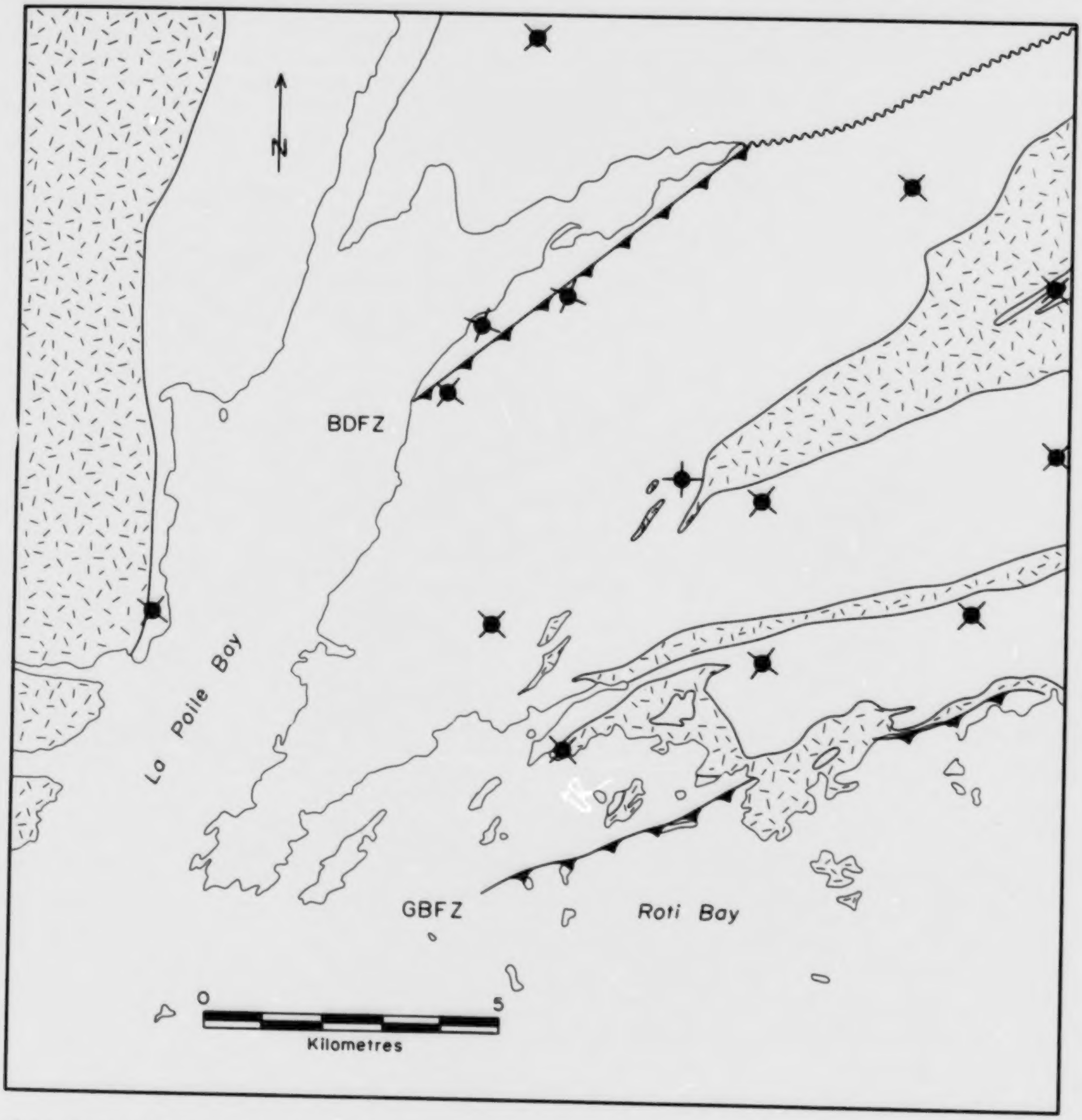


Figure 8. *Map of the La Poile Bay–Roti Bay area illustrating zones of silicic, pyritic or sericitic alteration (stars). Note the proximity of alteration zones to syntectonic intrusive rocks (stipled), and the Bay d'Est (BDFZ) and Grand Bruit (GBFZ) fault zones.*

members belonging to six major lithofacies. The most extensive units, the Whittle Hill sandstone and the Gallyboy Harbour tuff, are located near the structural top and base of the group, respectively. The Gallyboy Harbour tuff comprises a thick, laterally continuous deposit of water-laid, felsic crystal tuff near the stratigraphical top of the La Poile Group. The Whittle Hill sandstone is composed of continentally derived, texturally mature, quartzose sediments, which form the stratigraphically lowest exposed part of the La Poile Group. The primary features of the other complexly arranged members of the Georges Brook Formation are well preserved in an essentially steeply dipping, 5-km thick, homoclinal succession, which occurs in the negligibly strained internal portion of a crustal-scale thrust sheet.

Northwesterly directed, step-shaped, D_{lg} thrust faults separate low-grade rocks of the Late Silurian La Poile Group from rocks of high metamorphic grade in structurally overlying and underlying thrust sheets. The highest thrust sheet contains the Lower Ordovician Bay du Nord Group and the Ordovician or older Cinq Cerf gneiss, whereas the lowest thrust sheet is composed solely of the Bay du Nord Group. In this part of the metamorphic hinterland of southwest Newfoundland, ductile Acadian thrusts display large-scale 'flats' and 'ramps', which contrast strongly with the equivalent brittle structures observed in most foreland thrust belts. Near the 'flats' and 'ramps' of the Bay d'Est and Grand Bruit faults, for example, bedding-parallel, amphibolite-facies, S_{1a} schistosity in the Bay du Nord Group and S_{1a} gneissosity in the Cinq Cerf gneiss are concordant with bedding-parallel, greenschist-facies, S_{1g} slaty cleavage in the La Poile Group. Subhorizontal and subvertical belts of D_{1g} mylonite occur at the 'flats' and 'ramps' of thrusts, respectively. In the La Poile Group, the transition from upright to recumbent structures produces a partial flower structure or half-fan of slaty cleavage and bedding that is consistent with northwestward translation of the thrust sheets.

Although the relative or absolute ages of primary cleavage, schistosity and gneissosity are unproven, the writer tentatively suggests that they have two or possibly three distinct ages based on the presence of clasts with preincorporation foliations in the Bay du Nord and La Poile groups. The regional S_{1g} slaty cleavage developed in the Late Silurian between the accumulation of La Poile volcanics and their intrusion by granitoids. However, the S_{1a} schistosity probably formed during an earlier episode of recumbent folding and synamphibolite-facies thrusting that affected sedimentary and volcanic strata of the Bay du Nord Group. These post-Lower Ordovician, pre-Upper Silurian thrust sheets were exposed and provided high-grade metamorphic detritus to deposits in the La Poile depocentre. However, the Bay du Nord Group itself contains clasts of Cinq Cerf gneiss and Roti Granite. This might indicate the existence of older post-Lower Cambrian, pre-Lower Ordovician thrust sheets that were eroded and the resulting sediment deposited in the Bay du Nord depocentre. It also suggests that S_{1a} gneissosity in the Cinq Cerf gneiss is much older and formed at much greater depths than S_{1a} schistosity in the Bay du Nord Group. This history of metamorphism differs from and may predate that described from other parts of the Gander Zone, where isograds are commonly concentrically arranged about domal welts of migmatite and syntectonic plutons (Colman-Sadd, 1985; O'Neill, 1987).

Regardless of whether they are steep or flat, all intrusive bodies in the La Poile Bay–Roti Bay area were intruded during regional D_{2g} deformation; more specifically, intrusions postdated recumbent F_{1a}, and upright and recumbent F_{1g} folding but predated cessation of upright F_{2g} folding. Intrusions that appear to be 'forcefully' injected as sheets are emplaced along pre-existing foliations or fold-axial surfaces during periods of horizontal D_{2g} extension, which was intermittently brittle and ductile. For example, vertical, dyke-filled fractures parallel to the upright axial surfaces of periclines were produced by brittle failure, whereas horizontal sills near thrust 'flats' developed concordant (pre-F_{2g}) foliation by lateral ductile flow. As steep beds carrying S_{1g} cleavage were extended horizontally near the tops of underlying granites and gabbros, gently plunging bending folds were created due to the buttressing effect of massive intrusions or the spreading lobes of diapiric bodies. These extensional folds locally flattened the original subvertical S_{1g} cleavage and bedding into subhorizontal attitudes immediately prior to the formation of vertical fractures filled with resurgent magma (O'Brien, 1987).

Margin-parallel foliations in upright dykes and sills formed by vertical ductile flow, a process that achieved horizontal shortening of intrusions and neighbouring host rocks. It explains: 1) the localization of upright F_{2g} folds near the margins of intrusions, 2) the coaxial and coplanar relationship between S_{2g} crenulation cleavage and the primary foliation in intrusions, and 3) the fact that the most voluminous swarms of strongly foliated intrusions are hosted by rocks that have suffered the largest D_{2g} strains. Where upright dykes transected thrust 'flats' or gently dipping limbs of bending folds, wall rocks had either S_{1a} or S_{1g} foliation in the F_{2g} buckling field and, therefore, S_{2g} crenulation cleavage developed parallel to dyke margins. In places, vertical sheet intrusions containing steep internal foliations form either T-junctions with, or crosscut both margins of, flat-lying, concordantly foliated sills. This not only implies that brittle and ductile deformation overlapped, but also that upward ductile flow during vertical extension was contemporaneous with lateral ductile flow during horizontal extension.

The inhomogeneous horizontal shortening achieved by F_{2g} folding, S_{2g} crenulation cleavage and D_{2g} mylonitization is due to the complex interplay of horizontal and vertical extension near intrusive bodies. D_{1g} thrust faults and intervening thrust sheets are folded by large-scale D_{2g} domes that are cored by syntectonic intrusions. The rise of magma within these probably gravity-driven domes was checked by two competitive processes. Upright doming and subvertical extension faulting thinned the crust as magmas rose and deep-seated metamorphic rocks were tectonically uplifted. In contrast, horizontal extension produced vertical dilatant fractures filled with granite and gabbro, which thickened the crust. These processes interacted in an effort to maintain a constant-volume crust. However, horizontal extension also permitted the lateral flow of magma and the ponding of laccolithic bodies, which spread the rising magmas over increasing widths of crust. Vertically flowing offshoots from laterally flowing bodies signalled the upward readvance of magmas.

From the perspective of the geology of the La Poile Bay–Roti Bay area, alteration and gold mineralization are probably related to synmetamorphic, syntectonic plutons sited near regional fault lineaments (following Wilton and Strong, 1986).

ACKNOWLEDGMENTS

I am grateful to Brian Wheaton for his skilled field assistance and excellent companionship. Brian and I would like to thank the people of Grand Bruit, especially the family of George, Edna, Sim and Ches Billard, for simply being who they are. Pilots extraordinaire from Viking Helicopters and Universal Helicopters maintained our life support system. Field discussions with Peter Stewart, Colin McKenzie, Lesley Chorlton, Greg Dunning, Sean O'Brien, Steve Colman-Sadd, Jean van Berkel, Frank Blackwood and Hank Williams were an invaluable aid. Thorough manuscript reviews by Jim Connolly and Sean O'Brien are greatly appreciated.

REFERENCES

Blackwood, R.F.
1985: Geology of the Grey River area, southwest coast of Newfoundland. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 153-164.

Brown, P.A.
1973: Possible cryptic suture in southwest Newfoundland. Nature, Volume 245, Number 140, pages 9-10.

1976: Ophiolites in southwest Newfoundland. Nature, Volume 264, pages 712-715.

Chorlton, L.B.
1978: The geology of the La Poile map area (11O/9), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-5, 14 pages.

1980: Geology of the La Poile River area (11O/16), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-3, 86 pages.

Chorlton, L.B. and Dallmeyer, R.D.
1986: Geochronology of Early to Middle Paleozoic tectonic development in the southwest Newfoundland Gander Zone. Journal of Geology, Volume 94, pages 67-89.

Colman-Sadd, S.P.
1985: Geology of the Burnt Hill map area (2D/5), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-3, 94 pages.

Cooper, J.R.
1954: The La Poile-Cinq Cerf map area, Newfoundland. Geological Survey of Canada, Memoir 276, 62 pages.

Davenport, P.H. and Nolan, L.W.
1987: Gold and associated elements in lake sediment from regional surveys in the Port aux Basques area (NTS 11O) and the White Bay area (NTS 12H/9, 10, 11, 15, 16 and 12I/1). Newfoundland Department of Mines, Mineral Development Division, Open File Nfld 1582, 25 pages.

Dunning, G.R. and Chorlton, L.B.
1985: The Annieopsquotch ophiolite belt of southwest Newfoundland: geology and tectonic significance. Geological Society of America Bulletin, Volume 96, pages 1466-1476.

Dunning, G.R., Krogh, T.E., O'Brien, S.J., Colman-Sadd, S.P. and O'Neill, P.P.
In press: Geochronologic framework for the Central Mobile Belt in southwestern Newfoundland and the importance of Silurian Orogeny. Program with Abstracts, Joint Annual (1988) Meeting of the Geological Association of Canada, Mineralogical Association of Canada and Canadian Society of Petroleum Geologists, St. John's, Newfoundland.

Hayes, A.O. and Johnson, H.
1938: Geology of the Bay St. George Carboniferous area. Bulletin of the Geological Survey of Newfoundland, Number 12, 62 pages.

McConnell, J.W.
1987: Gold and associated trace elements in Newfoundland lake sediment from four areas of known gold mineralization. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File Nfld 1509.

O'Brien , B.H.
1987: The lithostratigraphy and structure of the Grand Bruit–Cinq Cerf area (parts of NTS areas 11O/9 and 11O/16), southwestern Newfoundland. *In* Current Research Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 311-334.

O'Brien, S.J., Dickson, W.L. and Blackwood, R.F.
1986: Geology of the central part of the Hermitage Flexure area, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 189-208.

O'Neill, P.P.
1987: Geology of the Weir's Pond map area (2E/1), Newfoundland. Newfoundland Department of Mines, Mineral Development Division, Open File Map 87-84, 1:50,000 scale.

O'Neill, P.P. and Strong, D.F.
1988: The Isle aux Morts Prospect: the first significant base metal discovery in the Port aux Basques Complex of southwest Newfoundland. CIM Bulletin, Volume 81, pages 59-68.

van Berkel, J.T.
1987: Geology of the Dashwoods Pond, St. Fintan's and Main Gut map areas, southwest Newfoundland. *In* Current Research, Part A. Paper 87-1A, pages 399-408.

Wilton, D.H.C. and Strong, D.F.
1986: Granite-related gold mineralization in the Cape Ray Fault Zone, southwestern Newfoundland. Economic Geology, Volume 81, pages 281-295.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 127-134

GEOLOGY OF THE SNOWSHOE POND (12A/7) MAP AREA

Stephen Colman-Sadd
Newfoundland Mapping Section

ABSTRACT

Mapping at a scale of 1:50,000 has been completed in the Snowshoe Pond area. Stratified rocks are placed in two main divisions. Those north of the major tectonic boundary of Noel Paul's Line consist of Ordovician volcanic and sedimentary rocks, and belong in the Dunnage Zone. Those south of the line consist exclusively of quartzitic and pelitic metasedimentary rocks and are placed in the Gander Zone. Granitic plutons range from pre- to posttectonic. Syn- and posttectonic granite and posttectonic mafic intrusions cut across Noel Paul's Line.

Two new units have been identified in the area. These are the syntectonic granite at Wilding Lake and a gabbro that is probably part of the Valentine Lake quartz monzonite intrusive suite. Other units described previously have been traced across the map area, and mafic volcanic rocks occurring at Rodeross Lake in the west and Lake Douglas in the east, appear to be correlative.

Clastic metasedimentary rocks of the Gander Zone show an increase in metamorphism southward from biotite, through andalusite, to sillimanite grade and then pass into migmatite. They form a complex fold interference pattern with pretectonic granite in the west of the area, and are cut by a regionally important postmetamorphic fault.

New occurrences of wolframite have been discovered in quartz veins cutting granite in the south of the area. Volcanic rocks of the Dunnage Zone and the lineaments defined by Noel Paul's Line and the Rogerson Lake Conglomerate are along strike from significant discoveries of gold and base metals at Valentine Lake and Duck Pond. Therefore, they are very promising targets for mineral exploration.

INTRODUCTION

During 1987, the author completed 1:50,000 mapping in the Snowshoe Pond area (Figure 1). The area is located about 40 km south of Buchans in the centre of Newfoundland's Central Mobile Belt (Williams, 1964) and lies astride the boundary between the Dunnage and Gander zones of Williams *et al. (in press)*. It is accessible from Millertown by the hydro-development roads to Granite Lake and Ebbegunbaeg Dam, and by logging roads to Quinn and Rodeross lakes.

Work done during 1987 consisted principally of extending previously defined units across the western one third of the map area. Only two new units were encountered and these were only seen in a total of four exposures. The reader is therefore referred to Colman-Sadd (1987a) for detailed descriptions of most of the units in this report.

Colman-Sadd (1987a) gave a comprehensive summary of previous work within the Snowshoe Pond area, including published studies and unpublished assessment reports. The only new information available since then is a Newfoundland Department of Mines open file 1:50,000 geological map of the entire area (Colman-Sadd, 1987b).

GENERAL GEOLOGY

The Snowshoe Pond area is underlain by two distinct sequences of stratified rocks that are cut by a variety of plutonic intrusions.

In the northwest, volcanic and sedimentary rocks are typical of the Exploits Subzone of the Dunnage Zone (Williams, 1978; Williams *et al.*, *in press)* and the Central Volcanic Belt (Kean *et al.*, 1981). West of Lake Douglas, they consist principally of Ordovician mafic volcanic rocks with extensive volcanogenic sedimentary units (Units 7 to 9), presumed to be unconformably overlain or in fault contact with the Silurian(?) Rogerson Lake Conglomerate (Unit 10) (Kean and Jayasinghe, 1980). The rocks to the northwest of the Rogerson Lake Conglomerate have been traditionally included in the Victoria Lake Group (Kean *et al.*, 1981); the similarity of those to the southeast suggests that they too should be included in the group. East of Lake Douglas, a sequence of felsic volcanic rocks and associated sedimentary rocks (Units 3 to 6) form a fault-bounded wedge. Although distinct from the rocks to the west in volcanic composition, these rocks do have a Dunnage Zone affinity because of their mixed volcanic and sedimentary nature. All of the rocks

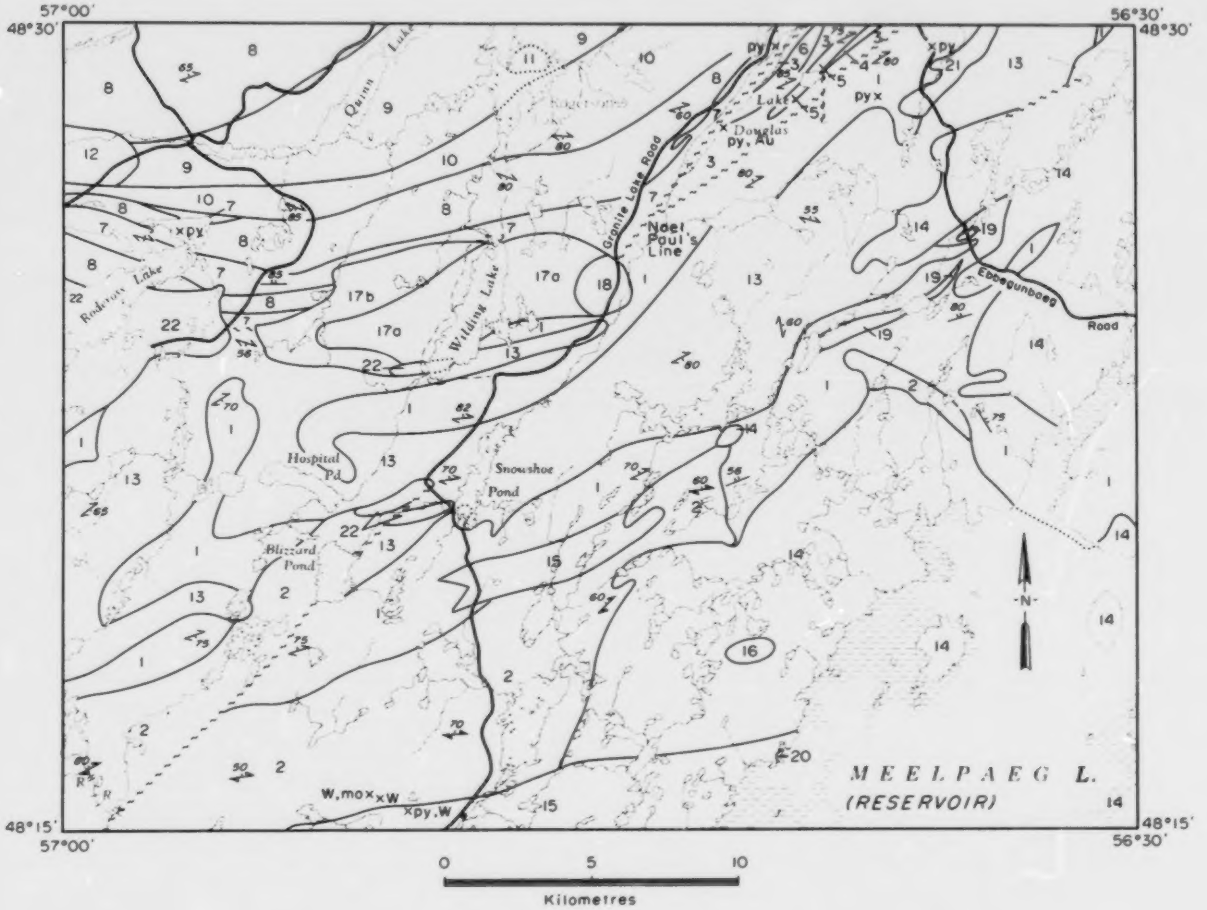


Figure 1. *Geological sketch map of the Snowshoe Pond (12A/7) map area.*

included in the Dunnage Zone within the map area are only slightly to moderately deformed by one principal deformation, and are metamorphosed to the greenschist facies.

The southern and eastern three quarters of the map area contain only one unit of stratified rocks, consisting of interbedded quartzite, psammite and pelite (Unit 1), and a unit of migmatite (Unit 2) derived from them. These rocks are placed in the Meelpaeg Subzone of the Gander Zone (Williams *et al.*, *in press*). The contact between the Exploits and Meelpaeg subzones (Noel Paul's Line) is a ductile shear zone where it is exposed, but is obscured by later intrusions along about half of its length within the Snowshoe Pond area. It has a southwest trend near Lake Douglas, but then swings westward to Rodeross Lake. The metasedimentary rocks of the Meelpaeg Subzone, tentatively correlated with the Ordovician Spruce Brook Formation of Colman-Sadd and Swinden (1984), were intruded pretectonically by mafic dykes, and have undergone two pervasive periods of deformation. Metamorphism varies from greenschist facies in the northwest to upper-amphibolite facies in the south, where an extensive area of sillimanite-grade metasedimentary rocks passes into migmatite.

Plutonic intrusions fall into three categories: 1) those that are restricted to the Exploits Subzone, 2) those that are restricted to the Meelpaeg Subzone, and 3) those that are common to both subzones. In the first category are several small gabbro intrusions, an intrusion of gabbro that is probably related to the Valentine Lake quartz monzonite (Unit 12), and one intrusion of granite (Unit 11). All of these are intruded by mafic dykes that are likely to be of about the same age as the mafic volcanism (Ordovician). In the second category are several granitoid bodies that probably range in age from Silurian to Devonian. Of these, the highly deformed biotite granite of Unit 13 appears to be terminated by the fault defining Noel Paul's Line between Rodeross and Wilding lakes, and so may predate movement on this fault; it has been affected by all the structural events that deformed the metasediments of the Meelpaeg Subzone. The other granitoid rocks restricted to the subzone (Units 14 to 16, 19 to 21) are considerably less deformed and are mostly related to the North Bay Granite. They are not physically terminated by Noel Paul's Line, and their general similarity to the granites at Wilding Lake (Units 17 and 18), which cut Noel Paul's Line, suggests that their restriction to the Meelpaeg Subzone is fortuitous. Apart from the granites at Wilding Lake, which

LEGEND

PLUTONIC INTRUSIONS

SILURIAN AND/OR DEVONIAN

22 *Equigranular, medium- to fine-grained, grey, biotite–pyroxene–hornblende gabbro; includes unseparated pyroxenite, and gabbroic and granitic pegmatite*

21 *Equigranular, medium grained, white, muscovite–biotite granite*

20 *Equigranular, medium grained pink syenite(?)*

19 *Garnet–tourmaline–muscovite granite pegmatite*

18 *Feldspar-porphyritic to equigranular, medium grained, grey to pink, biotite granodiorite; unfoliated or locally slightly foliated*

17 *Moderately foliated and locally lineated medium grained, grey biotite granite; 17a, K-feldspar porphyritic; 17b, equigranular*

NORTH BAY GRANITE (Units 14 to 16)

16 *Equigranular, medium grained, white, muscovite–garnet granite (not exposed in situ)*

15 *Equigranular, medium grained, grey to buff, biotite–muscovite granodiorite; locally slightly foliated*

14 *Feldspar-porphyritic to equigranular, medium grained, grey to pink, biotite granodiorite; locally slightly foliated*

13 *Equigranular to feldspar-megacrystic, medium grained, grey to pink, biotite granite; foliated, commonly mylonitic and commonly polydeformed*

ORDOVICIAN(?)

12 *Equigranular, medium grained, hornblende gabbro; slightly foliated; probably part of Valentine Lake intrusive suite*

11 *Equigranular, medium grained, grey to pink, chlorite–biotite granite*

DUNNAGE ZONE

SILURIAN(?)

10 ROGERSON LAKE CONGLOMERATE: *purple, clast-supported, polymictic conglomerate and minor sandstone*

CAMBRIAN AND ORDOVICIAN

VICTORIA LAKE GROUP (Unit 9 and part of Unit 8, north of Rogerson Lake Conglomerate)

9 *Mafic volcanic rocks, diabase dykes and small gabbro intrusions*

8 *Sedimentary rocks composed mainly of sandstone, siltstone and shale, but also including conglomerate; minor unseparated felsic crystal tuff, mafic volcanic rocks and small gabbroic intrusions.*

7 *Mafic pillow lava, pillow breccia, massive flows, and small gabbro intrusions*

6 *Crystal–lithic felsic tuff, and rhyolite flows and/or subvolcanic intrusive rocks*

5 *Clast-supported conglomerate composed mainly of felsic volcanic clasts*

4 *Grey quartz–feldspar, crystal–lithic felsic tuff*

3 *Grey parallel- and cross-laminated shale, siltstone and sandstone; includes strongly deformed rocks on Noel Paul's Brook that contain bands of limestone and mafic volcanic and/or intrusive rocks*

GANDER ZONE

ORDOVICIAN

2 *Migmatite, rich in biotite schlieren and metasedimentary fragments; derived from Unit 1 by Silurian(?) metamorphism and gradational into Unit 14 of North Bay Granite*

1 *Interbedded quartzite, psammite, semipelite and pelite, intruded by unseparated mafic dykes (probably equivalent to Spruce Brook Formation)*

Mineral Occurrences

Pyrite	*py*
Gold	*Au*
Molybdenite	*mo*
Tungsten	*W*

Symbols

Bedding, tops unknown (inclined)	
Cleavage (inclined, vertical)	
Gneissosity (inclined)	

vary from moderately deformed to completely posttectonic, the third category consists of the Rodeross Lake mafic–ultramafic intrusion (Unit 22). This appears fresh and undeformed, but has steeply dipping cumulate layering, indicating that it has been tilted. It has yielded a preliminary K/Ar date of 405 Ma (A. Hayatsu, personal communication, 1988).

PREVIOUSLY UNDESCRIBED UNITS

Unit 12

Logging operations during 1987 have created a new exposure on a northwesterly branch of the Quinn Lake–Victoria Lake road, near the western edge of the map area. The exposure consists of medium grained, equigranular, slightly pyritiferous, hornblende gabbro, containing inclusions of dark-green, fine grained, mafic volcanic rock. Both the gabbro and the volcanic rock have a slight inhomogeneous tectonic fabric. The gabbro has been cut by an east-southeast-trending mafic dyke, and by a few narrow quartz veins.

The new exposure is located about 2 km along strike from occurrences of quartz monzonite and gabbro that form an intrusive suite around Valentine Lake in the Victoria Lake area (Kean, 1977, 1982). The suite was referred to in the report of Colman-Sadd (1987a), but not shown on his map because at that time no exposures had been located in the Snowshoe Pond area.

Unit 17

Colman-Sadd (1987a) showed two granitoid units around Wilding Lake. The oldest of these is the strongly deformed biotite granite of Unit 13. The younger is an equigranular, medium grained, grey or pink, biotite granodiorite of Unit 18, which locally has a slight fabric and which is exposed principally on the Granite Lake road. It was formerly thought to extend to Wilding Lake (Colman-Sadd, 1987a) but is now considered to be restricted to an area well east of the lake. The newly defined granite intrusion of Unit 17 crops out at only three places, but it is the source of extensive boulder fields that have been used to estimate its areal extent.

The granite of Unit 17 is medium grained, grey or pink, and in most places contains biotite as the only primary mica. Its eastern variety (subunit 17a; Plate 1) is porphyritic, containing euhedral lath-shaped phenocrysts of potassium feldspar up to 4 cm long, but the variety (subunit 17b) that is dominant in the west is equigranular. Veins of the distinctive porphyritic variety and of possibly associated garnet–tourmaline–muscovite granite cut metasedimentary rocks of Unit 8 and granite of Unit 13 between Rodeross and Wilding lakes. An intrusive contact of subunit 17b into mafic volcanic rocks of Unit 7 is also exposed in this area.

Granite of Unit 17 has a moderate, planar, or locally linear, penetrative fabric. It is distinctly more deformed than granodiorite of Unit 18, and distinctly less deformed than granite of Unit 13. The latter relationship is demonstrated in the exposure of Unit 13 adjacent to Noel Paul's Line between the Rodeross Lake intrusion and the granite of Unit 17. Here mylonitic granite (Unit 13) is crosscut by deformed, but nonmylonitic, veins of porphyritic and equigranular granite (Unit 17; Plate 2).

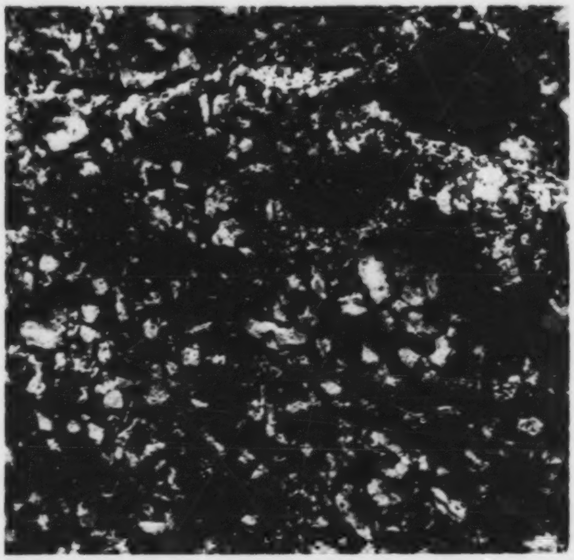


Plate 1. *Moderately foliated, porphyritic biotite granite of subunit 17a, west of Wilding Lake.*

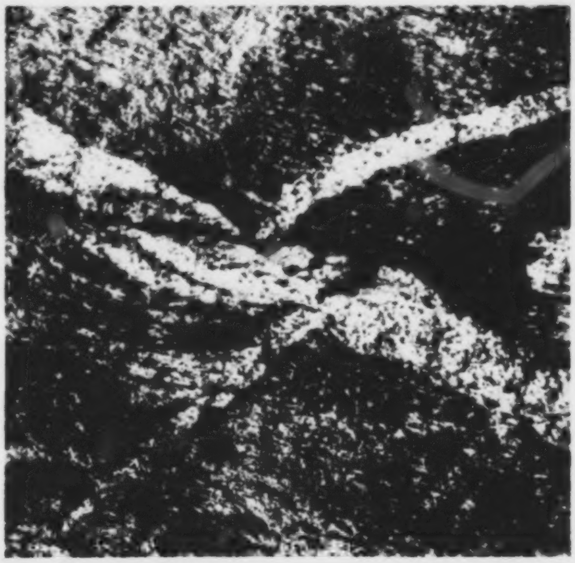


Plate 2. *Slightly deformed granite veins of Unit 17 cutting mylonitic granite of Unit 13, adjacent to Noel Paul's Line, southeast of Rodeross Lake.*

CONTINUATION OF PREVIOUSLY DESCRIBED UNITS

Most of the area mapped during 1987 is underlain by units described by Colman-Sadd (1987a) from other parts of the area.

North of the Rogerson Lake Conglomerate, mapping during 1987 failed to yield any new exposure (except in Unit 12, see above). The nonplutonic rocks in this area are divided into Units 8 and 9. The mafic volcanic rocks, dykes and gabbro intrusions at Rogerson Lake are placed in a single unit (Unit 9) because the absence of exposure does not justify separating them anywhere beyond the west shore of Rogerson Lake.

The Rogerson Lake Conglomerate (Unit 10) can be traced by scattered exposures southwest from Rogerson Lake to the Rodeross Lake road. Beyond that there is an exposure gap extending to the east edge of the Victoria Lake area (Kean, 1982). Constraint by exposures of other units indicates a considerably narrower outcrop than was envisaged by Colman-Sadd (1987a), and more in keeping with the 200-m width shown by Kean (1982).

Dunnage Zone units south of the Rogerson Lake Conglomerate appear on the gradiometer map (Geological Survey of Canada, 1985) to maintain continuity from Lake Douglas to Rodeross Lake. The sparse geological evidence supports this conclusion. Mafic volcanic rocks (Unit 7), including pillow lava, can be traced eastward from Rodeross Lake to 2 km northwest of Wilding Lake (Plate 3). They are then projected across an exposure gap of about 7 km to correlate with the northeast-trending pillow lavas that form the northwest shore of Lake Douglas. Outcrop areas of mafic volcanic rocks, without definite pillow lava, occur at the north end of Rodeross Lake and adjacent to Noel Paul's Line to the east of the lake. They are separated from the main part of Unit 7 by belts of clastic sedimentary rocks (Unit 8; Plate 4). A particularly prominent horizon of complexly folded pelite occurs immediately to the north of the main mafic volcanic outcrop at Rodeross Lake. This horizon is tentatively correlated with similar rocks extending from the west edge of the area almost to the Granite Lake road. Metasedimentary rocks that are poorly exposed in the brook between Wilding and Rogerson lakes were equated on a preliminary basis with Unit 1 by Colman-Sadd (1987a,b); they are now thought more likely to be part of the sedimentary sequence of Unit 8.

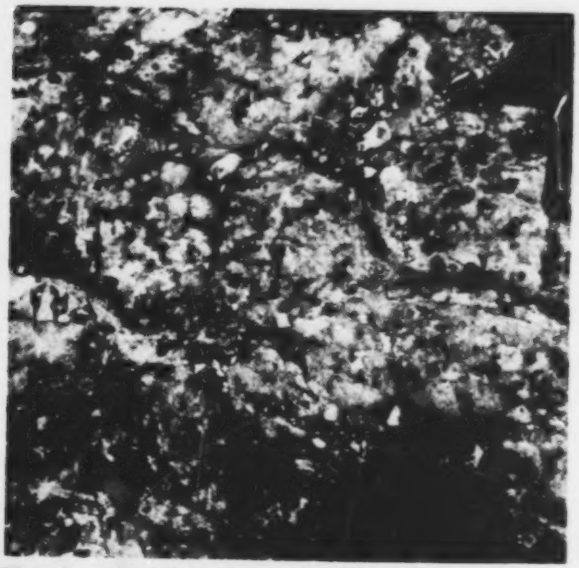


Plate 3. *Mafic pillow lava of Unit 7, northwest of Wilding Lake.*

Plate 4. *Interbedded sandstone and shale of Unit 8, southeast of Rodeross lake.*

South of Noel Paul's Line, the only metasedimentary unit is the interbedded quartzite and pelite of Unit 1 (Plate 5). The northern outcrop area extends southwest from Lake Douglas to the Granite Lake road where it is thought to bifurcate; one branch is projected across an area of no exposure to Wilding Lake, and the other can be traced to north of Hospital Pond. It is uncertain whether the latter branch is continuous with the main outcrop area to the northeast, or whether they are in fact separated by foliated granite of Unit 13.

The southern outcrop area of Unit 1 can be traced southwestward from Meelpaeg Lake to Blizzard Pond, where it is faulted against migmatite (Unit 2; Plate 6). The migmatite grades into metasediments of Unit 1, and forms outcrop areas separated by foliated granite (Unit 13). The map pattern west of Snowshoe Pond has been determined by sparse bedrock

Plate 5. *Quartzite interbedded with sillimanite schist, Unit 1 in southwest corner of map area.*

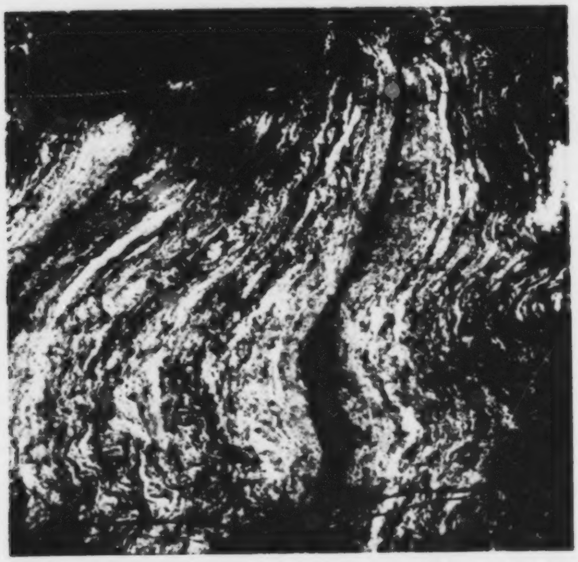


Plate 6. *Migmatite (Unit 2), just west of Blizzard Pond.*

exposure, supplemented by gradiometer data (Geological Survey of Canada, 1985).

In general, the main foliation in exposures of Unit 1 in the west part of the map area is the first deformation cleavage. This is commonly folded into tight, second-deformation folds and a second cleavage is developed in some places. Metamorphism increases from biotite grade, southeast of Lake Douglas, to andalusite grade, north and northwest of Hospital Pond, and to sillimanite grade, south and west of Blizzard Pond. The sillimanite-grade metasediments of Unit 1, grade southward into schlieren migmatite of Unit 2. The sedimentary protolith of the migmatite is clearly indicated by ubiquitous quartzitic and pelitic inclusions; occasional amphibolitic inclusions probably represent the mafic dykes that cut rocks of Unit 1. The migmatite front is excellently exposed about 1 km east of the fault that cuts through Blizzard Pond.

The oldest of the plutonic intrusions south of Noel Paul's Line is the foliated biotite granite of Unit 13. The main outcrop areas previously defined east of Snowshoe Pond can be traced westward to the western edge of the map area. The granite becomes especially mylonitic between Hospital Pond and Rodeross Lake. The main fabric appears to correspond with the first-deformation fabric recognized elsewhere in the granite and with the first-deformation fabric of the Unit 1 metasediments. Tight second-deformation folds are common in exposures of the granite southeast of Rodeross Lake (Plate 7).

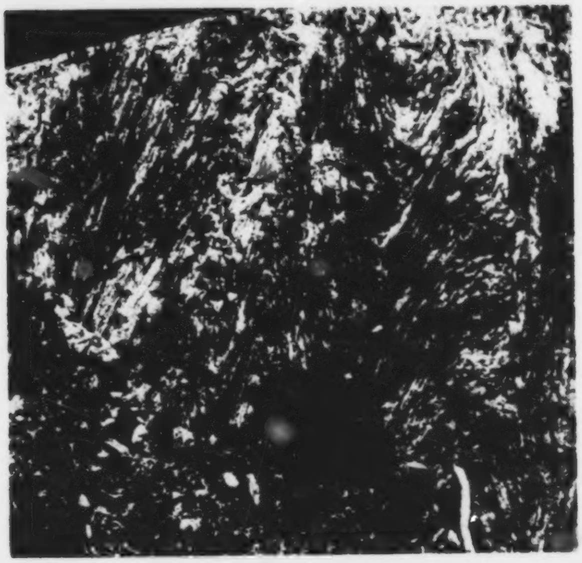


Plate 7. *Second-deformation folds in mylonitic granite of Unit 13 between Rodeross Lake and Hospital Pond.*

The largely posttectonic granitoid rocks, grouped with the North Bay Granite, are represented in the south-central part of the map area by equigranular, medium grained, biotite and biotite–muscovite granodiorite (Unit 15). The granodiorite is exposed along the south edge of the map area. Its contact with the migmatite (Unit 2) to the north has a marked topographic expression, but is not exposed. It is probably either a fault or sharp intrusive contact. The granite is cut by pyritic, muscovite–garnet pegmatite veins and by quartz veins that carry pyrite and wolframite.

The youngest rocks in the map area belong to the mafic–ultramafic Rodeross Lake intrusion and similar smaller bodies at Wilding Lake and Snowshoe Pond (Unit 22). Work done during 1987 has helped to define the extent and age of these rocks, but has added no other new information. Where exposure is particularly bad, e.g., west of Snowshoe Pond, the map pattern is based principally on gradiometer data (Geological Survey of Canada, 1985).

PRINCIPAL TECTONIC STRUCTURES

The map pattern in the western half of the Snowshoe Pond area is controlled by three main tectonic features, Noel Paul's Line, the Blizzard Pond fault and the complex interference of two generations of folds west of Snowshoe Pond.

Noel Paul's Line

The line marks the contact between rocks of the Dunnage and Gander zones. East of Lake Douglas, it is marked by a fault that separates a sequence of felsic metavolcanic and metasedimentary rocks (Units 3 to 6) from quartzites and pelites of Unit 1. This fault converges, southwest of the lake, with another fault marking the southeast boundary of the pillow lavas of Unit 7, and these faults are then presumed to be cut by the granitoid intrusions at Wilding Lake. The line is drawn as a continuation of the trend of the Lake Douglas fault, but it could equally well have been drawn as a continuation of the fault southeast of Lake Douglas, since there is no exposure between the point of convergence and the posttectonic granodiorite of Unit 18.

Most of Noel Paul's Line is obscured in the western half of the area by the Wilding Lake and Rodeross Lake intrusions. The only place where the line reappears (but is not exposed) is for about 1 km southeast of the Rodeross Lake road. Here, there is an exposure gap of 700 m (or 300 m perpendicular to strike) between mylonitic granite of Unit 13 (Plate 2) and mafic, possibly pillowed, volcanic rock (Unit 7) with a slight tectonic fabric. Both exposures have been intruded by veins of Unit 17 granite, with a moderately developed planar fabric.

Blizzard Pond Fault

The effects of the fault are most clearly seen southwest of Blizzard Pond where the fault displaces the migmatitic front separating Unit 1 metasedimentary rocks from Unit 2 migmatites. This segment of the fault gives rise to a strong topographic lineament, and exposures of migmatite close to the fault trace are strongly sheared; pegmatite veins that are generally posttectonic have been isoclinally folded and cleaved. Farther to the southwest, where migmatite occurs on both sides, there is little evidence for the fault, but in the Wolf Mountain (12A/2) area to the south, it shows up again as the prominent lineament forming the west shore of the northern arm of Granite Lake.

Northeast of Blizzard Pond, sheared migmatite occurs along Noel Paul's Brook and there is an apparent offset of an anomaly on the gradiometer map (Geological Survey of Canada, 1985). The anomaly is thought to be caused by a small mafic intrusion (Unit 22). The fault cannot be traced any farther northeast than this. Mylonitic granite occurs at Snowshoe Pond, but this is widespread in Unit 13 and there is no reason to attribute it to relatively late faulting. Northeast of Snowshoe Pond, the regional strike has the same trend as the fault, which may be undetected as a layer parallel structure. The fault's projection is exactly in line with the contact between metasediments of Unit 1 and foliated granite of Unit 13, south of Lake Douglas.

Polyphase Folding

West of Showshoe Pond, a complex map pattern in Units 1 and 13 shows significant divergence from the regional strike, as defined by the linear trend of Dunnage Zone units to the north and the strike of foliation in migmatites (Unit 2) to the south. The map pattern can be discerned to a limited extent from bedrock exposures. It has also been interpreted in areas of poor exposure using gradiometer data (Geological Survey of Canada, 1985), since metasedimentary rocks of Unit 1 have an anomalously high magnetic vertical gradient when compared with the foliated granite of Unit 13.

The map pattern west of Snowshoe Pond is attributed to interference of first and second deformation folds, with the added complication that originally, the metasediments and the granite may not have been interlayered in a regular way. Measured fold axes of both generations generally plunge at more than 45° in a variety of directions. The outcrop pattern of Unit 1, north of Hospital Pond, is suggestive of a type 3 interference pattern (Ramsay, 1967), in which the two sets of fold axes are about parallel, but the axial planes are at a high angle.

MINERAL POTENTIAL

Colman-Sadd (1987a) described six potentially mineralized exploration targets in the Snowshoe Pond area. They are:

1. tungsten–molybdenum mineralization associated with the younger granitoid intrusions (Units 14 to 19);
2. base- and precious-metal potential in mafic volcanic rocks (Units 7 to 9);
3. base- and precious-metal potential in felsic volcanic rocks (Units 4, 6 and 8);
4. potential for lineament-related gold mineralization along Noel Paul's Line;
5. similar mineralization in intensely deformed, pyritiferous quartzite and pelite (Unit 1), southeast of Noel Paul's Line, and
6. potential for platinum-group-element concentrations in the mafic–ultramafic Rodeross Lake intrusion (Unit 22).

Mapping during 1987 has further defined the extent of these targets and has located new occurrences of wolframite near the southern edge of the area. This mineralization occurs in pyritiferous quartz and greisen veins about 10 to 30 cm wide that cut biotite granodiorite of Unit 15. The veins are probably related to those carrying molybdenite and wolframite in migmatites (Unit 2) to the north (Tuach and Delaney, 1986).

The mineral potential of volcanic rocks in the area has been emphasized by the discovery of anomalous gold values in altered felsic volcanic rocks a few kilometres to the north, between Rogerson Lake and Lake Ambrose, and by the major Duck Pond massive sulphide discovery by Noranda. The latter deposit occurs farther north and approximately along strike in the Victoria Lake Group (Kean and Evans, *this volume)*.

BP-Selco's gold find at Valentine Lake is in a mainly quartz monzonite intrusive suite (Kean and Evans, *this volume)* that is probably represented in the Snowshoe Pond area by the single gabbro exposure in Unit 15. The showing is adjacent to the long, narrow belt of Rogerson Lake Conglomerate (Unit 10) which appears to be the molasse infill of a substantial Silurian(?) topographic lineament. The control on mineralization at Valentine Lake is at present uncertain, but if it is related to tectonism or fluid movement along this lineament, potential for similar occurrences exists adjacent to the Rogerson Lake Conglomerate in the Snowshoe Pond area (see also Kean and Evans, *this volume)*.

ACKNOWLEDGMENTS

Gerry Kilfoil provided an interpretation of the Geological Survey of Canada gradiometer data, and shared information from his own geophysical investigations in the Snowshoe Pond area. Akio Hayatsu gave permission for publication of his preliminary K/Ar date on the Rodeross Lake intrusion. Anthony Benoit is thanked for his usual excellent assistance with the field work. The manuscript was critically read by Brian O'Brien and Baxter Kean, whose comments resulted in many improvements.

REFERENCES

Colman-Sadd, S.P.
1987a: Geology of part of the Snowshoe Pond (12A/7) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 297-310.

1987b: Snowshoe Pond, Newfoundland. Newfoundland Department of Mines, Mineral Development Division, Open File Map 87-87.

Colman-Sadd, S.P. and Swinden, H.S.
1984: A tectonic window in central Newfoundland? Geological evidence that the Appalachian Dunnage Zone may be allochthonous. Canadian Journal of Earth Sciences, Volume 21, pages 1349-1367.

Geological Survey of Canada
1985: Aeromagnetic vertical gradient map, Snowshoe Pond, Newfoundland, scale 1:50,000. Geophysical Series, Map C41141 G.

Kean, B.F.
1977: Geology of Victoria Lake map area (12A/6), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-4, 11 pages.

1982: Victoria Lake, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File Map 82-9.

Kean, B.F. and Jayasinghe, N.R.
1980: Geology of the Lake Ambrose (12A/10)—Noel Paul's Brook (12A/9) map areas, Central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-2, 29 pages.

Kean, B.F., Dean, P.L. and Strong, D.F.
1981: Regional geology of the Central Volcanic Belt of Newfoundland. *In* The Buchans ore bodies: fifty years of geology and mining. *Edited by* E.A. Swanson, D.F. Strong and J.G. Thurlow. Geological Association of Canada, Special Paper 22, pages 65-78.

Kean, B.F. and Evans, D.T.W.
This volume: Regional metallogeny of the Victoria Lake Group.

Ramsay, J.G.
1967: Folding and fracturing of rocks. New York, McGraw-Hill, 568 pages.

Tuach, J. and Delaney, P.W.
1986: Granite Lake—Meelpaeg Lake: geological and mineral occurrence compilation. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File Map 86-69.

Williams, H.
1964: The Appalachians in northeastern Newfoundland—a two sided symmetrical system. American Journal of Science, Volume 262, pages 1137-1158.

1978: Tectonic lithofacies map of the Appalachian orogen. Memorial University of Newfoundland, Map 1.

Williams, H., Colman-Sadd, S.P. and Swinden, H.S.
In press: Tectonic-stratigraphic subdivisions of central Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 88-1A.

Current Research (1988) Newfoundland Department of Mines
Mineral Development Division, Report 88-1, pages 135-144

A MAJOR DUCTILE SHEAR ZONE IN THE BAY D'ESPOIR AREA, GANDER TERRANE, SOUTHEASTERN NEWFOUNDLAND

M.A.J. Piasecki
Department of Geology
University of Hull
Hull, East Yorkshire, England

ABSTRACT

In the region of Bay d'Espoir, the volcanic–sedimentary Baie d'Espoir Group is interpreted as an allochthonous sheet. It is separated from the Little Passage Gneiss, an assemblage of schists and migmatites of the Gander Terrane, by a major zone of layer-parallel ductile shearing, locally 12 km wide.

Mylonites in the shear zone contain abundant kinematic indicators and a regionally penetrative stretching lineation, which is subhorizontal and trends west-southwest. In gently inclined rocks far removed from the Hermitage Bay Fault zone, mylonitic fabrics indicate that the shear zone is a gently inclined thrust ('strike-slip thrust') along which the Baie d'Espoir Group has been transported over the Little Passage Gneiss toward the west-southwest. Near the Hermitage Bay Fault zone, the foliations in the rocks steepen, and the layer-parallel shear zone becomes a steep zone of sinistral strike-slip (transcurrent) movement. The steepening is associated with a regional increase in metamorphic grade and extensive granitic magmatism, interpreted as accompanying and overlapping the shearing movements.

The shear zone in Bay d'Espoir closely resembles the shear zone described by Hanmer (1981) from the northeastern Gander Terrane. It is suggested that the Bay d'Espoir shear zone may be a segment of a major shear zone on which allochthonous sheets of rocks of Dunnage affinity (Baie d'Espoir, Davidsville groups) have moved over the Gander Terrane in a southwesterly direction, a direction parallel with the trend of the orogen.

INTRODUCTION

The rocks of the Gander Terrane (Zone) form an intervening belt between the Avalon Terrane, presumed to be underlain by sialic crust, and the Dunnage Terrane, underlain by oceanic crust (Figure 1; Williams, 1979; Williams *et al.*, 1974). There is general consensus that the Gander and Avalon terranes are separated by the Hermitage Bay Fault zone, a complex zone of ductile to brittle movements. In contrast, the nature of the boundary between the Gander and Dunnage terranes is not as well defined. Clearly, the interpretation of the geology and tectonics of the Gander Terrane is critical to an understanding of the evolution of terranes in central Newfoundland. In southwestern Newfoundland, there is little consensus on the geology and the interpretation of the Gander Terrane. This contribution represents an attempt to resolve some of the controversies in that region, and to assess the implications for the geology and tectonics of the Gander Terrane as a whole.

Gander Terrane in Northeastern Newfoundland

The northeastern Gander Terrane has long been separated into three units, which, from west to east, are respectively the Gander Group, the Square Pond Gneiss and the Hare Bay Gneiss. The Gander Group comprises thick, moderately metamorphosed psammites, largely of turbidite origin, and subordinate semipelites. Locally there is a well-developed pressure-solution cleavage (see Plate 1 in Dickson, 1987). The Square Pond Gneiss is also largely psammitic, lithologically resembles the Gander Group, and locally contains relics of an earlier pressure-solution cleavage (personal observation). The Hare Bay Gneiss forms a belt adjacent to the Dover Fault, and consists of complex granitoid orthogneiss, psammitic to semipelitic migmatites and amphibolitic gneisses, and numerous granite intrusions.

These units, once thought to represent cover and basement complexes, are now considered more likely to be variably metamorphosed, lateral equivalents of one another (Blackwood, 1978); but the Hare Bay Gneiss may well contain components of probable basement material as well as components of the Square Pond Gneiss (personal observation).

Along the northwestern flank of the Gander Terrane, the beginning of the Dunnage Terrane is probably represented by the rocks of the Davidsville Group. These are weakly metamorphosed turbidites and shales (but locally staurolite schists), with olistostromes or mélanges, and with belts of mafic and ultramafic rocks. A discontinuous belt of such

---

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

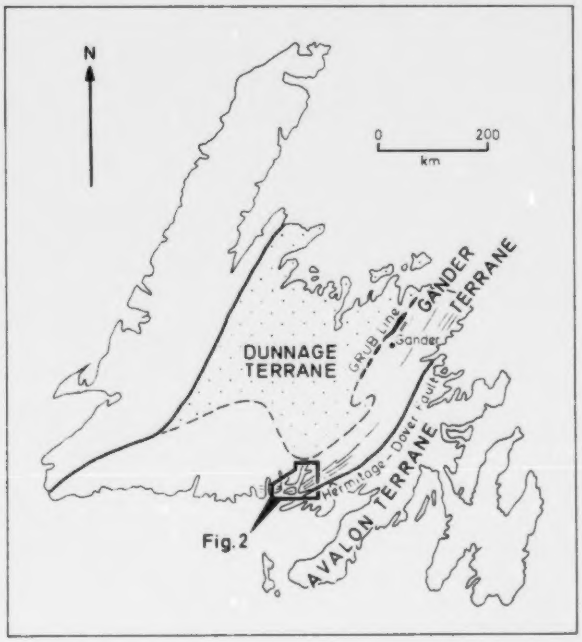


Figure 1. *Location of the area studied in relation to the terranes in central and eastern Newfoundland.*

rocks, the Gander River Ultrabasic Belt (the GRUB line; Figure 1) has been interpreted as marking a tectonic boundary between the Dunnage and Gander terranes (Blackwood, 1982). However, Pajari and Currie (1978) have indicated that the GRUB line represents a zone of mafic and ultramafic olistoliths within the black shales of the Davidsville Group. The critical contact between the Davidsville and Gander groups has been described as a conformable sedimentary transition (Pajari and Currie, 1978; Blackwood, 1982; Pajari *et al.*, 1979). However, the present author's preliminary examination of this contact southeast of the GRUB line, indicates that it is a tectonic break, defined by a zone at least 1 km wide, of ductile mylonites and ultramylonites developed from rocks of both assemblages. In this tectonic contact zone, numerous kinematic indicators, such as S–C foliations and shear bands *(sensu* Berthé *et al.*, 1979; see also Plates 1 and 2) indicate south- to southwest-directed sense of shear movements. This implies that the Davidsville Group has been thrust over the Gander Group, overriding it in a southwesterly direction.

The tectonics of the northeastern Gander Terrane have been the subject of an investigation by Hanmer (1981), who concluded that:

1) much of the region represents a zone of ductile, sinistral shearing some 60 km wide, of presumed Acadian age;

2) in this shear zone, the intensity of shear strain and of related metamorphic grade increased toward the Gander–Avalon boundary; and

3) the shearing was accompanied by emplacement of diapiric granites, most numerous within the belt of highest shear strain and maximum metamorphism, that is, in the Hare Bay Gneiss adjacent to the Dover Fault.

Gander Terrane in Southeastern Newfoundland

In the region of Bay d'Espoir (Figures 1 and 2), rocks of the Gander Terrane form a belt of psammitic and semipelitic schists and migmatites called the Little Passage Gneiss. These are structurally overlain by the Baie d'Espoir Group, an assemblage of metasedimentary and volcanic rocks, which may be more closely related to the Dunnage than to the Gander assemblage (cf. Colman-Sadd and Swinden, 1984). The Little Passage Gneiss forms a belt some 10 km wide, adjacent to the Hermitage Bay Fault zone. Like the Hare Bay Gneiss of the northeastern Gander Terrane, this belt of gneiss also includes a regional belt of steeply inclined rocks, is associated with the regional development of highest grade metamorphism, and is associated with the zone of most numerous granite intrusions. The regional metamorphic grade decreases toward the northwest, from sillimanite-bearing migmatite to garnet–staurolite–fibrolite schists in the Little Passage Gneiss, and from chlorite–biotite–garnet to chlorite–biotite in the Baie d'Espoir Group. The rocks of the Baie d'Espoir Group adjacent to the gneiss, are black, graphitic pelites and psammites with felsic and mafic tuffs and flows of the Isle Galet Formation. Northwestward, the Baie d'Espoir Group consists largely of turbiditic and shaly rocks of the Riches Island and St. Joseph's Cove formations.

In this southeastern region, controversy relates particularly to structural field observation and, in consequence, to the resultant interpretation of the regional tectonics and stratigraphy.

Early workers assigned all the metasediments in the Bay d'Espoir–Hermitage Bay region to a Baie d'Espoir Series (Jewell, 1939), later the Baie d'Espoir Group of Anderson (1967), believed to be of Ordovician age on the basis of fossil occurrences. Following detailed mapping in the Bay d'Espoir area, Colman-Sadd (1974, 1976; see also Colman-Sadd, 1980) interpreted the Little Passage Gneiss as a metasedimentary assemblage distinct from the rest of the Baie d'Espoir Group on structural–metamorphic and lithological grounds; such grounds include the confinement of a minor suite of muscovite–garnet–tourmaline granite and related pegmatite to the Little Passage Gneiss, and confinement of well-developed felsic volcanics to the Baie d'Espoir Group. He assigned the Little Passage Gneiss to a basement complex of Precambrian (?) age, upon which the Baie d'Espoir Group sediments were deposited. He interpreted the contact between these assemblages as a thrust (the Day Cove Thrust; Figure 2), in which the old structures in the gneisses were reworked and the inferred unconformity obliterated.

However, Blackwood (1985) in a report on the adjacent Facheux Bay map area that overlaps into Bay d'Espoir, concluded that there was no stratigraphic, structural or metamorphic evidence for significant dislocation or structural

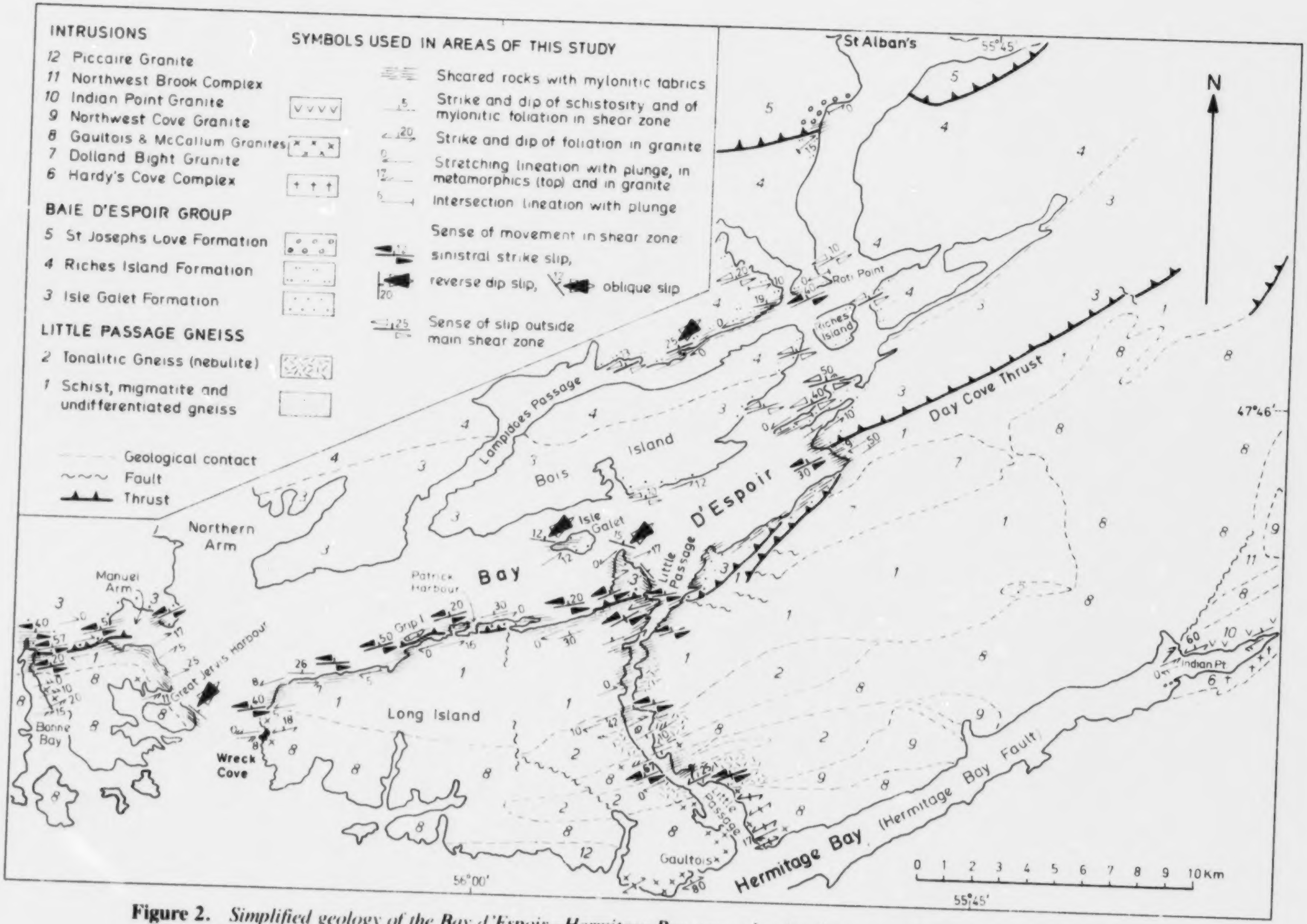

INTRUSIONS
12 Piccaire Granite
11 Northwest Brook Complex
10 Indian Point Granite
9 Northwest Cove Granite
8 Gaultois & McCallum Granites
7 Dolland Bight Granite
6 Hardy's Cove Complex
BAIE D'ESPOIR GROUP
5 St Josephs Cove Formation
4 Riches Island Formation
3 Isle Galet Formation
LITTLE PASSAGE GNEISS
2 Tonalitic Gneiss (nebulite)
1 Schist, migmatite and undifferentiated gneiss
Geological contact
Fault
Thrust
SYMBOLS USED IN AREAS OF THIS STUDY
Sheared rocks with mylonitic fabrics
Strike and dip of schistosity and of mylonitic foliation in shear zone
Strike and dip of foliation in granite
Stretching lineation with plunge, in metamorphics (top) and in granite
Intersection lineation with plunge
Sense of movement in shear zone:
sinistral strike slip,
reverse dip slip,
oblique slip
Sense of slip outside main shear zone
N
St Alban's
55°45'
Roti Point
Riches Island
Day Cove Thrust
47°46'
Lampidoes Passage
Bois Island
Isle Galet
D'Espoir
Bay
Little Passage
Northern Arm
Manuel Arm
Patrick Harbour
Grip I
Great Jervis Harbour
Bonne Bay
Long Island
Wreck Cove
Gaultois
Little Passage
Hermitage Bay
(Hermitage Bay Fault)
Indian Pt
56°00'
0 1 2 3 4 5 6 7 8 9 10 Km
55°45'

Figure 2. *Simplified geology of the Bay d'Espoir–Hermitage Bay area, showing the extent, the geometry and the sense of movement in the major shear zone. Geology, after Colman-Sadd and Swinden (1982), Colman-Sadd et al., (1979) and Blackwood (1985), listed in the left column of legend. Symbols in the central and left columns of legend refer only to the areas covered in this study.*

reworking between the Little Passage Gneiss and the Isle Galet Formation. On this basis, he effectively restored the original stratigraphy of Jewell (1939) and Anderson (1967), correlating the Little Passage Gneiss with stratigraphically higher units of the Isle Galet Formation.

In an attempt to resolve some of this controversy, in the summer of 1987 the writer carried out a four-week long, boat-supported investigation of the well-exposed shores of the Bay d'Espoir region, from Hermitage Bay in the east to Bonne Bay in the west (Figure 2).

BAIE D'ESPOIR GROUP–LITTLE PASSAGE GNEISS CONTACT ZONE

This contact zone was examined along the Harbour Breton highway (Route 360), along the coast of Bay d'Espoir, in Manuel Arm and in Bonne Bay (Figure 2). It was found to be followed by a major zone of ductile mylonites derived from the rocks of both assemblages. The zone of highest strain, in which ultramylonites (nomenclature after White, 1982) are well developed, corresponds with the trace of the Day Cove Thrust. However, mylonites and protomylonites are commonly developed over a zone up to some 10 km wide, as from Isle Galet into Little Passage, where the rock sequence may be partly repeated by folding and faulting. In Manuel Arm, the main mylonitic zone reaches a width of 2 km before it is cut by granite. Six kilometres north of the main zone, a related belt of rocks with less intense mylonitic fabrics, approximately one kilometre thick, follows the north shore of Lampidoes Passage.

Mylonitic Rocks in the Baie d'Espoir Group

The unit of the Baie d'Espoir Group that is in contact with the Little Passage Gneiss is the Isle Galet Formation. It consists of black pelite, commonly graphitic and generally phyllitic to schistose, which contains numerous beds of massive, felsic tuffs and rarer mafic rocks (Colman-Sadd, 1974, 1980; Blackwood, 1985).

As the black pelites are traced into the mylonitic zone, their bed-parallel foliation intensifies, the rocks become attenuated, such that in the zones of highest strain they become thinly layered phyllonites (phyllosilicate mylonites). They also develop subconcordant veinlets of quartz, which vary in size from microscopic to a few metres in length. Such veins are also present outside the mylonite zone, but they reach swarm proportions in the mylonitic rocks (Plate 1); some are surrounded by biotite–chlorite selvages, indicating probable derivation by the processes of strain-induced segregation. Such swarms of subconcordant quartz veins are typical of ductile shear zones at the base of the Fleur de Lys Supergroup, along the Baie Verte Line and in the southern Long Range in Newfoundland (Piasecki, 1987), in the Grenville Province of Ontario (personal observation), and in Scotland (Piasecki and van Breeman, 1983). The phyllonites in the high-strain zones contain pervasive developments of S–C mylonite foliations and shear bands (*sensu* Berthé *et al.*, 1979) that range in scale from 0.5 cm to more than 10 cm. This can impart to the phyllonites the appearance of 'button schist'. Excellent examples can be seen along the south coast of Bay d'Espoir near Patrick Harbour and on Grip Island (Plate 2).

The massive felsic volcanics, which locally form lenticular-shaped units within the phyllonites, also undergo progressive fabric changes. The tuffs and flows, often with phenocrysts of quartz and feldspar (see Plate 10 in Blackwood, 1985), develop a bed-parallel foliation, which intensifies, such that in zones of high strain the rocks become mylonites and ultramylonites. In many localities, as around The Barasway in Manuel Arm, such ultramylonites derived from felsic tuff become difficult to distinguish from ultramylonites derived from granite sheets in the Little Passage Gneiss. The felsic and mafic volcanics contain profuse developments of S–C mylonite foliations and shear bands (Plate 1). There are also rotated porphyroclasts (see Passchier and Simpson, 1986), small-scale asymmetric boudinage, and minor asymmetric folds. A stretching lineation also progressively develops in the volcanic rocks, and becomes very intense with increasing strain. It is defined by a parallel alignment of ribbons of granulated and dynamically recrystallized grains of quartz and feldspar (cf. Plate 3). In contrast with the competent felsic volcanic rocks, in which the stretching lineation forms a major element of the fabric, this lineation is only weakly developed in the less competent phyllonites.

It is now well known that these fabric elements are indicative of simple shear deformation and are typical of ductile thrust zones (Berthé *et al.*, 1979; White *et al.*, 1980; Hanmer, 1981; Simpson and Schmid, 1983; Lister and Snoke 1984; Weijermars and Rondeel, 1984; Ramsay and Huber, 1987). The profuse development of these fabric elements in the highly strained rocks around Bay d'Espoir clearly indicates the presence of a major ductile shear zone in this region.

Several minor belts of sheared rocks occur north of the main mylonite zone. These are more widely spaced, narrow in outcrop, and consist of weakly developed protomylonites with sigmoidal tension fractures, shear bands and occasional S–C foliations.

Mylonitic Rocks in the Little Passage Gneiss

The Little Passage Gneiss structurally underlies the Baie d'Espoir Group along a highly sheared contact marked by a spectacular development of mylonites and ultramylonites. Colman-Sadd (1974, 1976, 1980) recognized this contact as a tectonic boundary (the Day Cove Thrust). He also recognized that the movements on this thrust (assumed to have been toward the southeast) had reworked the Little Passage Gneiss for some distance below the thrust surface.

The Little Passage Gneiss is an assemblage of psammitic and some semipelitic schists and gneisses, with local development of amphibolitic schist and gneiss (for a detailed description see Colman-Sadd and O'Driscoll, 1979). Adjacent to the Baie d'Espoir Group, semipelitic mylonitic schists

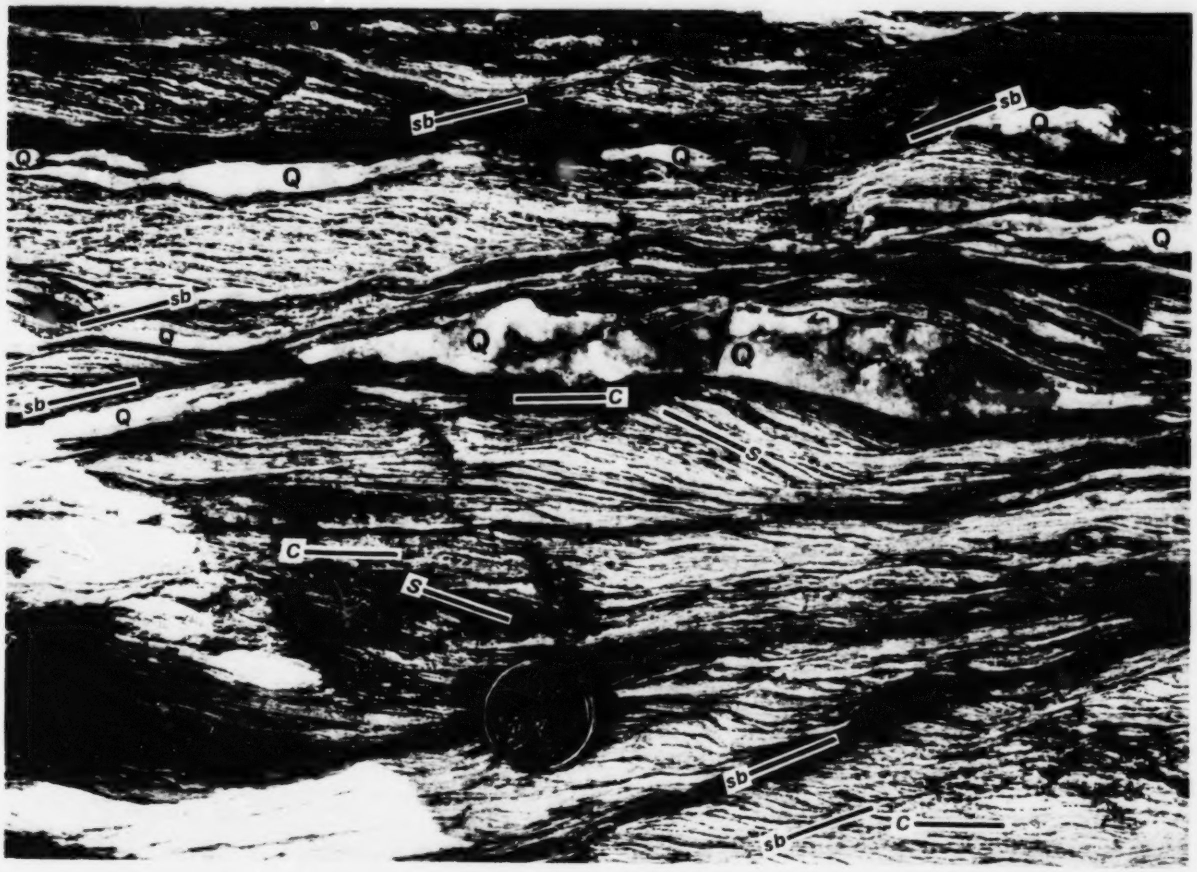


Plate 1. *Common indicators of simple shear strain and of the sense of movement in a sheared rock. Mylonite after felsic tuff, showing penetrative development of S-C foliation (S,C) and shear bands (sb). A swarm of segregation-type quartz veins (Q) emphasizes the slip on the shear bands. The sense of shear movement is left lateral; the plane of exposure is parallel to an intense stretching lineation (cf. Plate 3). Cliff at east end of bay immediately east of Patrick Harbour.*

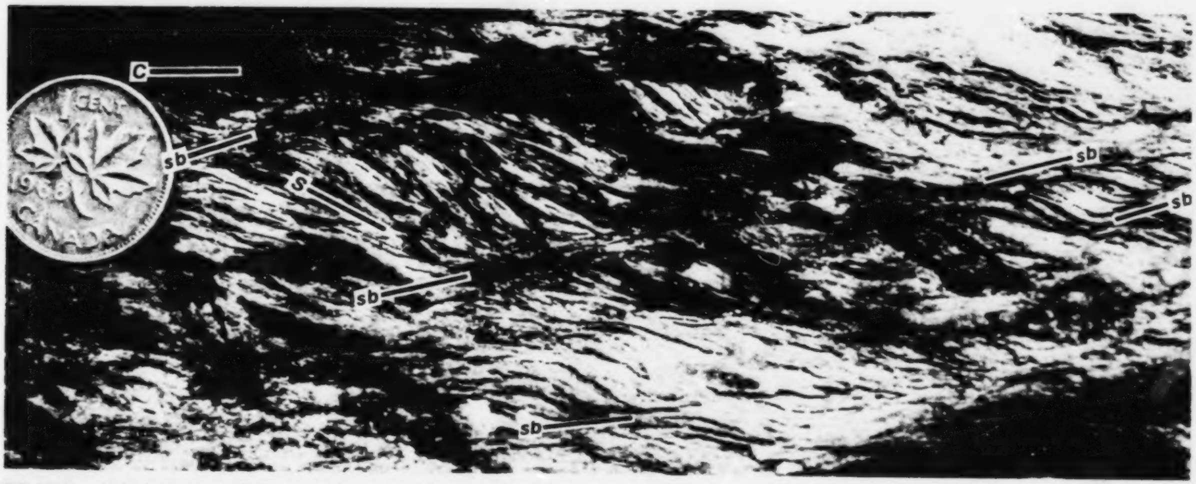


Plate 2. *S-C foliation (S,C) and shear bands (sb) forming incipient 'button schist' structure in phyllonite. Sense of movement is left lateral. South shore of Grip Island.*

Plate 3. *Intense stretching lineation, defined by aligned ribbons of granular aggregate of feldspar and quartz. These represent originally large grains in the granite, granulated and dynamically recrystallized into aggregates of small equigranular grains, then pulled out into ribbons in the direction of the maximum extension in the shear zone. Muscovite–tourmaline granite sheet in the Little Passage Gneiss, north shore of Long Island.*

contain garnet–fibrolite assemblages that appear to be syntectonic with the shearing movements. Locally, they contain posttectonic staurolite. Toward the Hermitage Bay Fault zone, the metasediments become progressively engulfed by voluminous granite, where they pass into coarse migmatites (see Plate 30 in Blackwood, 1985) and nebulites. Locally, these rocks are associated with gneisses that could represent elements derived from a deeper basement.

The Little Passage Gneiss rocks are mylonitic for at least 4 km south of their boundary with the mylonites of the Baie d'Espoir Group. Zones of protomylonitic to mylonitic, gneissic metasedimentary rocks can be seen amongst the granites for a farther 3 km, beyond which few metasediments have been observed. The mylonites adjacent to the Baie d'Espoir Group are well exposed along the northern shore of Long Island and along the southern shore of Manuel Arm. These mylonites, and locally protomylonites, contain swarms of subconcordant veinlets of quartz and of quartz–feldspar segregations, as well as developments of S–C mylonite foliations and shear bands. They also contain a stretching lineation, defined by the alignment of most of their constituent minerals, which is best seen in the psammitic rocks. Their mylonitic microfabric parallels a thinly laminated compositional layering that probably represents highly attenuated and modified bedding.

Mylonitic Minor Intrusions in the Little Passage Gneiss

The Little Passage Gneiss mylonites also contain numerous sheets of leucocratic, muscovite–garnet–tourmaline granite and of apparently related pegmatite. A striking feature of these minor intrusions is their high degree of deformation into mylonites and protomylonites, and their intense, penetrative mineral lineation (Plate 3), parallel to that in the host mylonitic metasediments.

The pegmatities vary in degree of deformation. More highly deformed pegmatites form 'porphyroclastic gneisses' comprising rotated and partly granulated and dynamically recrystallized feldspar augens, around which a matrix of recrystallized feldspar and quartz forms an anastomasing pattern. Locally, some of the less deformed pegmatite sheets can be seen to be more discordant to the layer-parallel mylonitic foliation of the host metasediments than the more highly deformed pegmatites. In one instance, the main body of a 20-m-long sheet can be seen to cut the C-fabric of the mylonitic metasediment along the plane of the regional S-fabric. In contrast, the terminations of this sheet bend into C-fabric, presumably having been rotated into it by a later increment of the C fabric. Such relationships may be taken to indicate that the minor intrusions were emplaced during the shearing event.

Zone of Granite Intrusion

Traced toward the Hermitage Bay Fault zone, the minor intrusions within the Little Passage Gneiss give way to progressively larger granitic bodies, culminating in a belt of plutons adjacent to Hermitage Bay (Figure 2). The metamorphic grade in the metasedimentary rocks increases toward this plutonic belt: the rocks become migmatitic, at first with minor developments of nebulitic granite, then with a wide zone of an inhomogeneous nebulitic granite (tonalitic gneiss of Colman-Sadd, 1980; and Unit 2 in Figure 2). The nebulite commonly preserves remnants of a layering and of compositional signatures of the original metasediments. These are now seen as belts of highly siliceous nebulite carrying schlieren of psammite, or of micaceous nebulite with kernels of biotite and prismatic kyanite retrogressed to aggregates of fine grained muscovite. These resemble sillimanite-biotite knots in nearby semipelitic migmatites. Locally, the nebulite contains traces of well-banded gneisses, which could represent fragments of a deeper basement, implying that some parts of the nebulitic granite may have been substantially mobile.

The nebulitic granite locally encloses screens of variably migmatized metasediments with strongly mylonitic fabrics. Also, the nebulite locally develops a strong mineral lineation, mylonitic S–C foliations and rotated porphyroclasts, all aligned parallel to corresponding fabrics in the mylonites of the main shear zone.

Farther southeastward, the nebulitic granite passes into coarser, more homogenized types. These, with development of megacrystic feldspar, in turn pass into still coarser, megacrystic, clearly intrusive rocks: such is the Gaultois Granite, which contains numerous schlieren of nebulite, and even developments of layering. In some cases, the layering is folded, and is reminiscent of 'ghost stratigraphy' structures in migmatitic granites. Good examples can be seen in Wreck Cove, Great Jarvis Harbour and in Bonne Bay (examples at the latter two localities are in the McCallum Granite of Blackwood, 1985). The Gaultois Granite is usually steeply foliated. At its boundaries with the mylonitic metasediments, the granite tends to deflect their mylonitic foliation into subparallelism with its contact. Locally it develops a mineral stretching lineation, sometimes sufficiently intense for the rock to become an L-tectonite. Its linear and foliar fabrics generally have the same orientation and attitude as those in the shear-zone mylonites (Figure 2), suggesting emplacement during the shearing movements, in a manner similar to that discussed by Hanmer (1981) for the emplacement of syntectonic granites in the northeastern Gander Terrane.

The foliated and lineated nebulite and the megacrystic granites are intruded by several generations of later granitic intrusions that become progressively more homogeneous in composition. The earlier generations are locally lineated parallel to the lineation in the shear zone, but less intensely than their hosts; they are cut by subsequent bodies free from deformation fabrics, indicating that the granitic activity had accompanied and outlasted the ductile shearing.

At the head of Hermitage Bay, a pink granite, the Straddling Granite of Blackwood and O'Driscoll (1976), appears to straddle the Hermitage Bay Fault zone. In the course of this work, no ductile deformation fabrics were observed in the granite on the Avalon Terrane (Figure 1) side of the fault, which contains belts of brecciation and thin shears which have generated pseudotachylite. On the Gander Terrane side of the bay, a pink granite contains a foliation and local development of a stretching lineation typical of the Gander Terrane (Figure 2). These observations are consistent with the geochemical and isotopic evidence quoted by Elias and Strong (1982) for the pink granite on the Gander side of the fault, the Indian Point Granite, being distinct and substantially younger than the Avalon counterpart, the Hardy's Cove Complex.

Folding

The rocks with the wide belt of shearing show the effects of two phases of folding related to the development of the shear zone.

The earlier folds are isoclinal to close, asymmetric minor structures that frequently grade into intrafoliated folds. At their hinges, they fold the lithological layering *and* the layer-parallel, mylonitic C-foliation with its swarms of quartz segregation veins, but their axial surfaces are defined by a mylonitic C-fabric with more quartz veins. Clearly, these folds must have formed during the shearing movements. The folded C-foliation and the axial-surface C-foliation correspond, respectively, to a shear fabric already attained before fold development, and a later increment of this fabric formed at the time of the folding. The fold hinges vary in orientation from parallelism with the stretching lineation, to attitudes as high as 60° to this lineation. Many have curvilinear hinges and some locally develop into sheath folds (Cobbold and Quinquis, 1980; Hanmer, 1981), indicating rotation into the maximum extension direction in the shear zone.

The later folds, which refold the asymmetric and intrafolial structures, are upright to steeply inclined, more open in profile, and range from minor structures to folds with wavelengths of the order of a kilometre. Their axial surfaces are commonly marked by steep- to upright-crenulation cleavages. The intersection of these cleavages with the main foliation defines an intersection lineation of common occurrence throughout the region. The fold hinges and this intersection lineation are subparallel to the regional shear-related stretching lineation. The upright folds are present throughout the region, but, as seen in Little Passage, they reach their maximum development in the belt of migmatite and granite. There, they fold the foliation in the nebulites and in the megacrystic granites; their hinges are parallel with the locally developed stretching lineation in the intrusives that are believed to be syntectonic with the shearing. The upright folding appears to be related to a subhorizontally directed flattening strain, which seems to have accompanied the later stages of the shearing movements. Locally, it has led to the development of minor sets of conjugate strain-slip cleavages that closely resemble synthetic and antithetic shear bands (see Lister and Snoke, 1984).

Sense of Tectonic Transport and Geometry of the Shear Zone

In the Bay d'Espoir region (Figure 2), the mylonitic rocks abound in fabric elements, which are well known to be generated by simple shear strain, and which can be used as kinematic indicators for determining the sense of tectonic movements in the shear zone (Simpson and Schmid, 1983; Passcher and Simpson, 1986; White *et al.*, 1986). The most useful are the S−C foliations and shear bands developed in almost all the mylonitic rocks (Plates 1 and 2), and the rotated feldspar porphyroclasts present in the mylonitic felsites of the Isle Galet Formation and in the mylonitic granite sheets and pegmatites within the Little Passage Gneiss. As seen in Figure 2, on the regional scale of Bay d'Espoir, in the main belt of shearing, and also in the zone of minor slip in Lampidoes Passage, these kinematic indicators systematically point to a sinistral (left lateral) strike-slip movement relative to the layer-parallel mylonitic foliation. Only in the Little Passage Gneiss immediately north of Great Jervis Harbour is this sense of movement not so clearly defined, and, in fact, it may be reversed, suggesting the possible presence of an overturned limb of a subrecumbent fold. The derived sense of regional shear transport is supported by the consistency in the orientation and attitude of the stretching lineation in all the mylonitic rocks within the shear zone, taken to correspond with the regional maximum extension axes (the X-axes).

Thus, along the shore of Bay d'Espoir, the thick zone of ductile shearing has the geometry of a gently inclined, layer-parallel zone of overthrusting toward the west-southwest.

The regional trend of the layer-parallel, mylonitic fabric changes locally, e.g., south of Manuel Arm, where it appears to have been deflected by the emplacement of granite. However, the mylonitic stretching lineation maintains its regional course without deflection, and related kinematic markers point to continued sense of transport toward the west-southwest. This relationship indicates that the granite may have been emplaced at the time of the shearing movements, deflecting the earlier formed mylonitic foliation, but being affected by the subsequent mylonitic fabric.

Traced southeastward along Little Passage into the higher grade rocks, the gently inclined, layer-parallel shear zone bends upward, reaching a subvertical attitude in the belt of syntectonic granite adjacent to the Hermitage Bay Fault zone. The sense of movement remains left-lateral, the geometry of the shear zone becomes that of a zone of subvertical strike-slip (transcurrent) movement.

SUMMARY AND CONCLUSIONS

On the Scale of the Bay d'Espoir Region

This work indicates that a major belt of ductile shearing, several kilometres thick and accompanied by regional amphibolite-facies metamorphism, separates the Baie d'Espoir Group from the Little Passage Gneiss. Along this shear belt, the volcanic and metasedimentary rocks of the Baie d'Espoir Group have been thrust to the west-southwest over the Little Passage Gneiss *in a direction subparallel to the trend of the Appalachian Orogen* in Newfoundland, and to the trend of the major terrane boundaries. This sense of tectonic transport, previously unrecorded in this part of the Gander Terrane, has been derived by systematic observation of abundant, clearly defined, kinematic indicators related to an intense, penetrative regional stretching lineation. Evidence for northwest-southeast movements has not been recorded.

This shear zone has the attitude of a gently inclined thrust in the region of Bay d'Espoir, but in the direction of the Hermitage Bay Fault zone it passes gradually into a steep zone of sinistral strike-slip movement. Its steep attitude corresponds with the zone of granite intrusions, believed to be syn- to late-tectonic with the shearing movements.

The relationship between the Baie d'Espoir Group and the Little Passage Gneiss has been previously interpreted as a lateral sedimentological transition (Blackwood, 1985) and as distinct assemblages (Colman-Sadd, 1974). The new data adds further support to the distinct nature of these assemblages, in that the Baie d'Espoir Group is allochthonous, transported for an unknown distance over the Little Passage Gneiss.

On the Scale of the Gander Terrane

The present observations from the southeastern Gander Terrane are remarkably consistent with the observations of Hanmer (1981) from the northeastern Gander Terrane.

The data of this study and that of Hanmer's (1981), collectively indicate that the whole eastern flank of the Gander Terrane in central Newfoundland corresponds with a major zone of ductile shearing. This shearing is expressed by overthrusting toward the southwest in a central flat belt, which then passes into sinistral strike-slip (transcurrent) movements within the steep belt of granite-injected rocks adjacent to the boundary with the Avalon Terrane. This zone of shearing could represent an initially subhorizontal overthrust upturned by the rise of the syntectonic granite diapirs (cf. Figure 9 in Hanmer, 1981). Alternatively, the subhorizontal thrusting may be related to more fundamental movements in a vertical transcurrent zone, perhaps associated with early, ductile stages of evolution of the Dover–Hermitage Bay Fault zone.

Tectonically significant is the new observation that in the northeastern Gander Terrane, the boundary between the Gander and Davidsville groups (the presumed boundary between the Gander and Dunnage terranes) is, at least locally, a zone of ductile shearing along which the Davidsville Group appears to have overthrust the Gander Group in a southwesterly direction. It suggests that the whole of the Gander Terrane *and* at least the eastern flank of the Dunnage Terrane represent a series of allochthonous slices that have travelled subparallel to the axes of the orogen.

Colman-Sadd and Swinden (1984) have proposed that the Baie d'Espoir, Davidsville and Victoria Lake groups may be members of an allochthonous Dunnage Terrane that has been thrust upon Gander (?) elements exposed in tectonic windows (Mount Cormack Terrane). On such a model, the Bay d'Espoir shear zone, and the shear zone observed at the boundary between the Gander and Davidsville groups north of the town of Gander, could be segments of a major zone of ductile thrusting at the base of this allochthon. In Bay d'Espoir, this thrusting may have cut out, perhaps along a lateral ramp, all the Gander elements other than the Little Passage Gneiss.

ACKNOWLEDGMENTS

I wish to express my thanks to S.P. Colman-Sadd for introducing me to the geology of the southwestern Gander Terrane, and for organizing and providing support for this field project; to Anthony Benoit for his professionalism and seamanship without which this work could not have been done; to Eve and Ed Collier, for their hospitality in St. Alban's; and to Pat O'Neill for hospitality and an introduction to the geology of the northeastern Gander Terrane.

REFERENCES

Anderson, F.D.
1967: Structural studies in the Baie d'Espoir Group, Newfoundland. *In* Collected papers on geology of the Atlantic region—Hugh Lilly Memorial Volume. *Edited by* E.R.W. Neale and H. Williams. Geological Association of Canada, Special Paper 4, pages 193-200.

Berthé, D., Choukroune, P. and Jegouzo, P.
1979: Orthogneiss, mylonite and noncoaxial deformation of granites: the example of the South Armorican Shear Zone. Journal of Structural Geology, Volume 69, pages 31-42.

Blackwood, R.F.
1978: Northeastern Gander Zone, Newfoundland. *In* Report of Activities for 1977. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 72-79.

1982: Geology of the Gander Lake (2D/15) and Gander River (2E/2) area, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-4, 56 pages.

1985: Geology of the Facheux Bay area (11P/9), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-4, 56 pages.

Blackwood, R.F. and O'Driscoll, C.F.
1976: The Gander-Avalon boundary in southeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 13, pages 1155-1159.

Cobbold, P.R. and Quinquis, H.
1980: Development of sheath folds in shear regimes. Journal of Structural Geology, Volume 2, pages 119-126.

Colman-Sadd, S.P.
1974: The geological development of the Bay d'Espoir area, southeastern Newfoundland. Unpublished Ph.D. thesis, Memorial University of Newfoundland, St. John's, 271 pages.

1976: Geology of the St. Alban's map area, Newfoundland (1M/13). Newfoundland Department of Mines and Energy, Mineral Development Division, Report 76-4, 19 pages.

1980: Geology of south-central Newfoundland and evolution of the eastern margin of Iapetus. American Journal of Science, Volume 280, pages 991-1017.

Colman-Sadd, S.P. and O'Driscoll, C.F.
1979: Geology of the Gaultois (1M/12) map area, Newfoundland. Unpublished report. Newfoundland Department of Mines and Energy, Mineral Development Division.

Colman-Sadd, S.P. and Swinden, H.S.
1982: Geology and mineral potential of south-central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-8, 102 pages.

1984: A tectonic window in central Newfoundland? Geological evidence that the Appalachian Dunnage Zone may be allochthonous. Canadian Journal of Earth Sciences, Volume 21, pages 1349-1367.

Colman-Sadd, S.P., Greene, B.A. and O'Driscoll, C.F.
1979: Gaultois map area (1M/12). Newfoundland Department of Mines and Energy, Mineral Development Division, Map 79104.

Dickson, W.L.
1987: Geology of the Mount Sylvester (2D/3) map area, central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 283-296.

Elias, P.N. and Strong, D.F.
1982: Timing of arrival of the Avalon Zone in the northeastern Appalachians: a new look at the Straddling Granite. Canadian Journal of Earth Sciences, Volume 19, pages 1088-1094.

Hanmer, S.
1981: Tectonic significance of the northeastern Gander Zone, Newfoundland: an Acadian ductile shear zone. Canadian Journal of Earth Sciences, Volume 18, pages 120-135.

Jewell, W.B.
1939: Geology and mineral deposits of the Baie d'Espoir area. Geological Survey of Newfoundland, Bulletin 17, 29 pages.

Lister, G.S. and Snoke, A.W.
1984: S-C mylonites. Journal of Structural Geology, Volume 6, pages 617-638.

Pajari, G.E. and Currie, K.L.
1978: The Gander Lake and Davidsville Groups of northeastern Newfoundland: a re-examination. Canadian Journal of Earth Sciences, Volume 15, pages 708-714.

Pajari, G.E., Pickerill, R.K. and Currie, K.L.
1979: The nature, origin, and significance of the Carmanville ophiolitic mélange, northeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 16, pages 1439-1451.

Passchier, C.W. and Simpson, C.
1986: Porphyroclast systems as kinematic indicators. Journal of Structural Geology, Volume 8, pages 831-843.

Piasecki, M.A.J.
1987: Strain induced mineral growth in ductile shear zones, and a preliminary study of ductile shearing in western Newfoundland, Project 850017. Unpublished report. Geological Survey of Canada, 30 pages.

Piasecki, M.A.J. and van Breemen, O.
1983: Field and isotopic evidence for a c. 750 Ma tectonothermal event in the Moine rocks in the Central Highland region of the Scottish Caledonides. Transactions of the Royal Society of Edinburgh, Earth Sciences, Volume 73, pages 119-134.

Ramsay, J.G. and Huber, M.I.
1987: The techniques of modern structural geology. Volume 2: Folds and Fractures. Academic Press, Orlando, Florida, 700 pages.

Simpson, C. and Schmid, S.J.
1983: An evaluation of criteria to deduce the sense of movement in sheared rocks. Geological Society of America, Bulletin, Volume 94, pages 1281-1288.

Williams, H.
1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 16, pages 792-807.

Williams, H., Kennedy, M.J. and Neale, E.R.W.
1974: The northeastward termination of the Appalachian Orogen. *In* The Ocean Basins and Margins. *Edited by* A.E.M. Nairn and F.G. Stehli. Volume 2. The North Atlantic. Plenum Press, New York, NW, pages 79-123.

Weijermars, R. and Rondeel, H.E.
1984: Shear band foliation as an indicator of sense of shear: field observations in central Spain. Geology, Volume 12, pages 603-606.

White, S.H.
1982: Fault rocks of the Moine Thrust Zone: a guide to their nomenclature. Textures and Microstructures, Volume 4, pages 211-221.

White, S.H., Bretan, P.G. and Rutter, E.H.
1986: Fault-zone reactivation: kinematics and mechanisms. Philosophical Transactions of the Royal Society of London, Series A, Volume 317, pages 81-97.

White, S.H., Burrows, S.E., Carreras, J., Shaw, N.D. and Humphreys, F.J.
1980: On mylonites in ductile shear zones. Journal of Structural Geology, Volume 2, pages 175-187.

Current Research (1988) Newfoundland Department of Mines,
Mineral Development Division, Report 88-1, pages 145-164

GEOLOGY AND MINERALIZATION IN THE HUNGRY GROVE POND (1M/14) MAP AREA, SOUTHEASTERN NEWFOUNDLAND

W. Lawson Dickson
Newfoundland Mapping Section

ABSTRACT

The Hungry Grove Pond (1M/14) map area straddles the boundaries between the recently proposed Avalon, Gander and Dunnage zones. The Avalon Zone in the map area comprises the upper Precambrian (Proterozoic III) Belle Bay and Rencontre formations of the Long Harbour Group, the Simmons Brook Batholith and late diabase dykes. To the northwest, and separated from the Avalon Zone by the Hermitage Bay Fault, the Gander and Dunnage zones consist of sedimentary and volcanic rocks of the Middle Ordovician and older Baie d'Espoir Group, including the Little Passage Gneiss, granitoids of the syntectonic North West Brook Complex, and the Lower Devonian posttectonic Koskaecodde pluton. Apart from the Baie d'Espoir Group, all units in the map area and the Hermitage Bay Fault are intruded by the 375 Ma Ackley Granite Suite. Glacial-flow indicators show that Pleistocene ice movement was towards 170°.

A small fault-bound sliver of magnesite occurs along the Le Pouvoir Fault, which is a strike-parallel fault within the Isle Galet Formation of the Baie d'Espoir Group. This fault separates the schistose felsic and mafic volcanic rocks and conformably underlying Little Passage Gneiss from the less-deformed sedimentary and volcanic rocks of the Isle Galet Formation and greywacke of the Riches Island Formation. High Cr and Ni values indicate that the magnesite has an ultramafic parentage. Thus the presence of magnesite indicates that the Le Pouvoir Fault is possibly a deep-seated thrust that has penetrated the oceanic crust basement to the Baie d'Espoir Group.

Stibnite ± gold mineralization occurs in chloritic mafic tuffs of the Isle Galet Formation and extensive quartz veining occurs along the Collins Brook Fault. The gold discoveries at Westfield Mineral's Little River prospects just to the west of the map area give the Isle Galet Formation a significant potential for further gold findings.

INTRODUCTION

The Hungry Grove Pond (1M/14) map area is located in southeast central Newfoundland, approximately 20 km east of Milltown, Bay d'Espoir. There are no settlements within the map area. Disused woods roads and Newfoundland Hydro roads provide access to the power line in the northern part of the map area, but only 'all-terrain vehicles' (ATVs) are suitable for these roads. The locally rugged terrain, swamps, boulder fields and forests hinder ATV access to areas outside the proposed wilderness reserve, which occupies the general area between the Bay du Nord River and North East Brook (Figure 1). Helicopters and float planes, available in the Bay d'Espoir area, provide the most efficient form of access to the wilderness reserve but only certified scientific surveys are permitted to use these forms of transportation. The western boundary of the wilderness reserve is still under discussion and may be moved slightly to the east to the western edge of the Bay du Nord River valley. Claim staking is not permitted in the proposed wilderness reserve.

The Baie d'Espoir Group is currently the focus of intense mineral exploration as it hosts significant gold ± stibnite showings that occur in two of the main volcanic horizons within the map area. This report is concerned mainly with the geology of the area west of the Ackley Granite Suite (Tuach, 1987). Detailed geology and geochemistry of the Ackley Granite Suite is given in Dickson (1983), Tuach *et al.* (1986) and Tuach (1987).

Regional Setting

Following the proposal of Williams *et al.* (1988) the Hungry Grove Pond map area (Figure 1) straddles the southeastern portions of the Gander and Dunnage zones and the western margin of the Avalon Zone (terrane of Williams and Hatcher, 1983). Williams *et al.* (1988) have proposed that the Baie d'Espoir Group (of Colman-Sadd, 1976), formerly part of the Gander Terrane (of Williams and Hatcher, 1983) be included in Exploits Subzone of the Dunnage Zone and that the generally higher grade metasedimentary rocks of the

---

This project is a contribution of the Canada–Newfoundland Mineral Development Agreement, 1984–1989

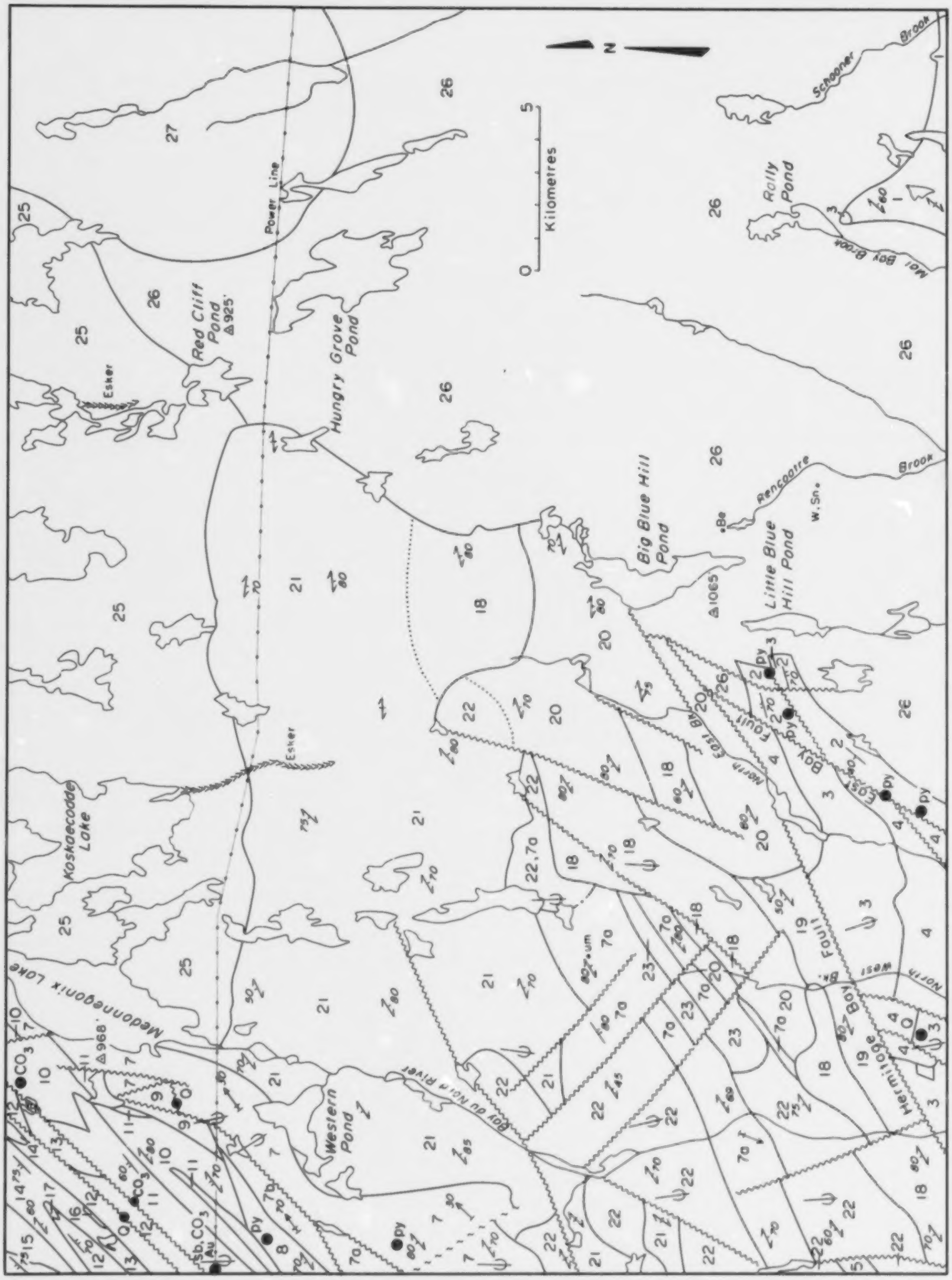

N
Kilometres
0
5
Koskaecodde Lake
Medonnegonix Lake
Esker
Red Cliff Pond
Δ925
Hungry Grove Pond
Power Line
Western Pond
Bay du Nord River
Big Blue Hill Pond
Δ1065
Little Blue Hill Pond
Rencontre Brook
Be
W, Sn.
Schooner Brook
Rolly Pond
Mal Bay Brook
North East Bk
North Bay Fault
East Bay Fault
North West Bk
Bay Fault
Hermitage
Δ968
CO3
Sb, CO3
Au
py
25
26
27
21
18
20
22
23
19
3
4
2
1

Figure 1. *Geology of the Hungry Grove Pond (1M/14) map area.*

LEGEND

DEVONIAN

ACKLEY GRANITE SUITE (Units 26 and 27)

27 *Pink and red, massive, coarse grained, leucocratic, equigranular, biotite granite and minor, fine grained, quartz–feldspar-porphyritic, biotite granite*

26 *Pink, massive, coarse grained, leucocratic, K-feldspar-porphyritic, biotite granite*

25 KOSKAECODDE PLUTON: *pink to grey, massive, coarse grained, K-feldspar-porphyritic, biotite granite; minor layered, massive, medium grained, equigranular biotite ± muscovite granite*

24 *Grey, massive, fine grained, diabase dykes*

SILURIAN–DEVONIAN

NORTH WEST BROOK COMPLEX (Units 18 to 23)

23 *Pink, foliated, fine grained, equigranular, biotite granite*

22 *Pink to buff, foliated, medium grained, equigranular and K-feldspar-porphyritic, biotite ± muscovite granite*

21 *Pink to buff, foliated, coarse grained, K-feldspar-porphyritic, biotite granite (cut by dykes of Unit 22)*

20 *Pink to buff, foliated, medium grained, equigranular, biotite ± muscovite granite*

19 *Buff to grey, foliated, medium grained, equigranular, biotite granodiorite*

18 *Orange to black, strongly foliated, coarse grained, feldspar-porphyritic, biotite granodiorite; 18a, massive, coarse grained, equigranular, biotite quartz diorite*

ORDOVICIAN OR SILURIAN

17 *Grey, foliated and sheared, medium grained, equigranular biotite granodiorite*

16 *Black, massive, coarse grained diabase; 16a, large, massive quartz veins*

ORDOVICIAN

BAIE D'ESPOIR GROUP (Units 7 to 15)

15 RICHES ISLAND FORMATION: *Grey, cleaved, medium bedded sandstone and slate*

ISLE GALET FORMATION–Units 7 to 14

14 *Medium- to coarse-grained, strongly cleaved, poorly sorted sandstone, pebble conglomerate and breccia containing abundant clasts of felsic volcanic rocks and quartz–sericite schist*

13 *Rhyolitic flows, bedded lapilli and fine grained tuff, and quartz–feldspar-crystal, ash-flow tuff*

12 *Grey, medium- to thick-bedded slate, siltstone and sandstone*

11 *Strongly deformed, chlorite ± sericite schist, and minor cleaved basalt flows, quartz–sericite schist and grey slate; 11a, chloritic semipelite and psammite*

10 *Strongly deformed, quartz–sericite ± chlorite schist (felsic metavolcanic rocks) and minor chlorite schist and slate*

9 *Pink to red, weakly cleaved, rhyolitic tuff and flows*

8 *Highly folded and quartz-veined, grey to black, locally rusty, pelite and semipelite*

7 LITTLE PASSAGE GNEISS: *highly deformed, grey to black, pelitic to psammitic, biotite schist and biotite gneiss and migmatite; 7a, dominantly pelitic biotite schist and minor psammitic biotite schist, containing locally extensive, rusty, micaceous alteration zones; 7b, quartz-rich, biotite psammite and semipelite*

(Legend continued on next page.....)

LEGEND

(Continued from previous page)

ORDOVICIAN OR OLDER

6 *Magnesite*

UPPER PRECAMBRIAN

SIMMONS BROOK BATHOLITH (Units 3 to 5)

5 *Grey, massive, medium- to fine-grained, diabase dykes*

4 *Pink to green, massive and locally brecciated, medium- to coarse-grained, equigranular, hornblende–biotite granodiorite*

3 *Black to dark-green, massive, medium- to coarse-grained, gabbro, diabase and minor pyroxenite*

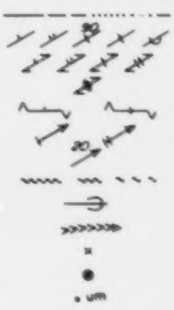
LONG HARBOUR GROUP (Units 1 and 2)

2 RENCONTRE FORMATION: 2a, *grey, massive, thick bedded, locally micaceous, sandstone hornfels;* 2b, *grey and brown, strongly cleaved, medium bedded sandstone and siltstone;* 2c, *medium bedded, pebble conglomerate and sandstone, minor thick bedded limestone*

1 BELLE BAY FORMATION: *grey to buff, flow-layered rhyolite, rhyolitic tuff, massive basaltic flows*

SYMBOLS

Geological boundary (defined, approximate, assumed, gradational)
Bedding, tops known, unknown (inclined, vertical, overturned)
Cleavage or schistosity, first, second generation (inclined, vertical)
Primary igneous flow layering (vertical)
Shear fabric (inclined, vertical)
Fold plunge and amount (first, second generation)
Mineral lineation with amount of plunge
Fault (defined, approximate, assumed)
Glacial striation–direction of ice movement known
Esker
Examined outcrop
Mineral occurrence
Ultramafic erratics



MINERAL OCCURRENCES

W	*tungsten*
Sn	*tin*
by	*beryl*
sb	*stibnite*
Au	*gold*
py	*pyrite*
Q	*quartz veining*
CO_3	*carbonate alteration or veining*
po	*pyrrhotite*
asp	*arsenopyrite*
gn	*galena*
sph	*sphalerite*

Little Passage Gneiss are a part of the Gander Lake Subzone of the Gander Zone. The boundary between the Dunnage Zone and Gander Lake Subzones is the Day Cove Thrust of Colman-Sadd (1974, 1976). The Avalon Zone is represented by small portions of the upper Precambrian (Proterozoic III) Long Harbour Group (Williams, 1971), which is widespread to the south in the Fortune Bay area, and the probable upper Precambrian Simmons Brook Batholith (Widmer, 1950), which continues to the southwest of the map area.

The Avalon and Gander zones are juxtaposed along the Hermitage Bay Fault (Widmer, 1950; Blackwood and O'Driscoll, 1976) and the extensive (2700 km^2) Ackley Granite Suite intrudes both zones (Figure 2). The Middle Devonian Ackley Granite Suite is the oldest rock common to both the Gander and Avalon zones and provides the minimum age of movement on the fault. There is no indication of fault-related features, common elsewhere along the Hermitage Bay Fault, such as fault brecciation, fracture-filling quartz veins, alteration of biotite or plagioclase in the Ackley Granite Suite, along the northeast projection of the fault in the Big Blue Hill Pond area. Tuach (1987) dated the Hungry Grove Granite (Unit 26) at 367–374 Ma. The geometric relationships between the East Bay and Hermitage Bay faults indicate that the East Bay Fault truncates the Hermitage Bay Fault. Two km west of Big Blue Hill Pond, brecciated and altered granite occurs within 150 m of the massive Ackley Granite Suite. The altered granite is similar to the Ackley Granite Suite but is identical to altered granite of the Simmons Brook Batholith exposed to the southwest and northeast of North East Brook, along the Hermitage Bay Fault. The Ackley Granite is here interpreted to have been emplaced along the fault.

The Little Passage Gneiss has been included in the Baie d'Espoir Group by Blackwood (1985). In this report, the gneisses are also considered to form part of a continuous succession with the Baie d'Espoir Group although, in places, the contact is faulted. Thus the Gander Lake Subzone may not be present in the map area.

Previous Work

The earliest recorded work in the area is a reconnaissance survey by Baird *et al.* (1951) and a regional geological survey of the Hamilton Sound to Bay d'Espoir area by the Photographic Survey Corporation (?1951). The Little River to Medonnegonix Lake area was surveyed locally in detail but most of the area was assessed by aerial photographic interpretation with only local ground checks.

The area west of Medonnegonix Lake and Western Pond was included in a regional survey (Moore, 1953) of the Sylvester Lake (Diamond Lake; Mount Sylvester 2D/3 map area) to Conne River and River Pond area (St. Alban's 1M/13 map area) in which the major lithotypes were outlined with some accuracy. Some now significant components of the succession, such as mafic chlorite schists, however, were not differentiated.

McCabe (*in* Berrangé and McCabe, 1955) mapped from Medonnegonix Lake to the western boundary of the map area. However, in contrast to Moore (1953), felsic and mafic schistose volcanic rocks were mapped as metasediments, an error included in the paper of Anderson (1967). In Anderson's (1965) 1:250,000 compilation map of the Belleoram (1M) map area, none of the detailed geology defined by Moore (1953) or Baird *et al.* (1951) was shown. A molybdenite–bismuthinite showing in the Big Blue Hill Pond area (Anderson, 1967) has not been located in subsequent surveys.

An aeromagnetic survey by the Geological Survey of Canada (1969) showed several prominent anomalies and these can now be seen to coincide with significant geological contacts or lithologies.

Blackwood (1975) mapped the area along the Hermitage Bay Fault, in the Hungry Grove Pond map area, as part of a regional study of the fault, and noted that the fault was defined by a narrow breccia zone 50 to 100 m in width.

Saunders and Prince (1977) carried out a VLF and magnetometer survey about 4 km north of the Le Pouvoir showing but obtained no significant geophysical anomalies.

Dean (1978) included the area west of Medonnegonix Lake in a regional exploration survey of the Kaegudeck Lake area and noted the presence of felsic pyroclastic rocks that earlier surveys had mapped as conglomerate. Virtually all lithofacies west of Medonnegonix Lake were mapped as felsic or mafic volcanic rocks.

Aerodat Limited (1979) carried out an airborne electromagnetic and magnetic survey in the Kaegudeck Lake to Little River area for Hudson's Bay Oil and Gas Company Limited. Two sizable anomalies were outlined in the area west of Medonnegonix Lake, as shown previously by the Geological Survey of Canada (1969).

Butler and Davenport (1979) carried out a lake-sediment geochemistry program that included the Hungry Grove Pond Map area. Mo, U and F anomalies were indicated in the Big Blue Hill Pond area and single-site Ni, Co and Zn anomalies occur in an area 8 km northeast of the Le Pouvoir Sb showing. The lake sediment anomalies within the Ackley Granite Suite were followed up by Rio Tinto Canadian Exploration (McKenzie, 1980) and Falconbridge Nickel Mines Limited (Saunders, 1980, 1981). However, only minor Mo and Zn values were obtained from stream, soil, and rock samples.

Dickson *et al.* (1980) and Dickson (1982, 1983) carried out a reconnaissance lithogeochemical survey that included all the granitoid rocks in the Hungry Grove Pond map area, as outlined by Anderson (1967). This survey showed that the distribution of the Ackley Granite was distinctly different from that shown by Anderson (1967) and that the area southwest of Hungry Grove Pond was underlain by a variety of deformed

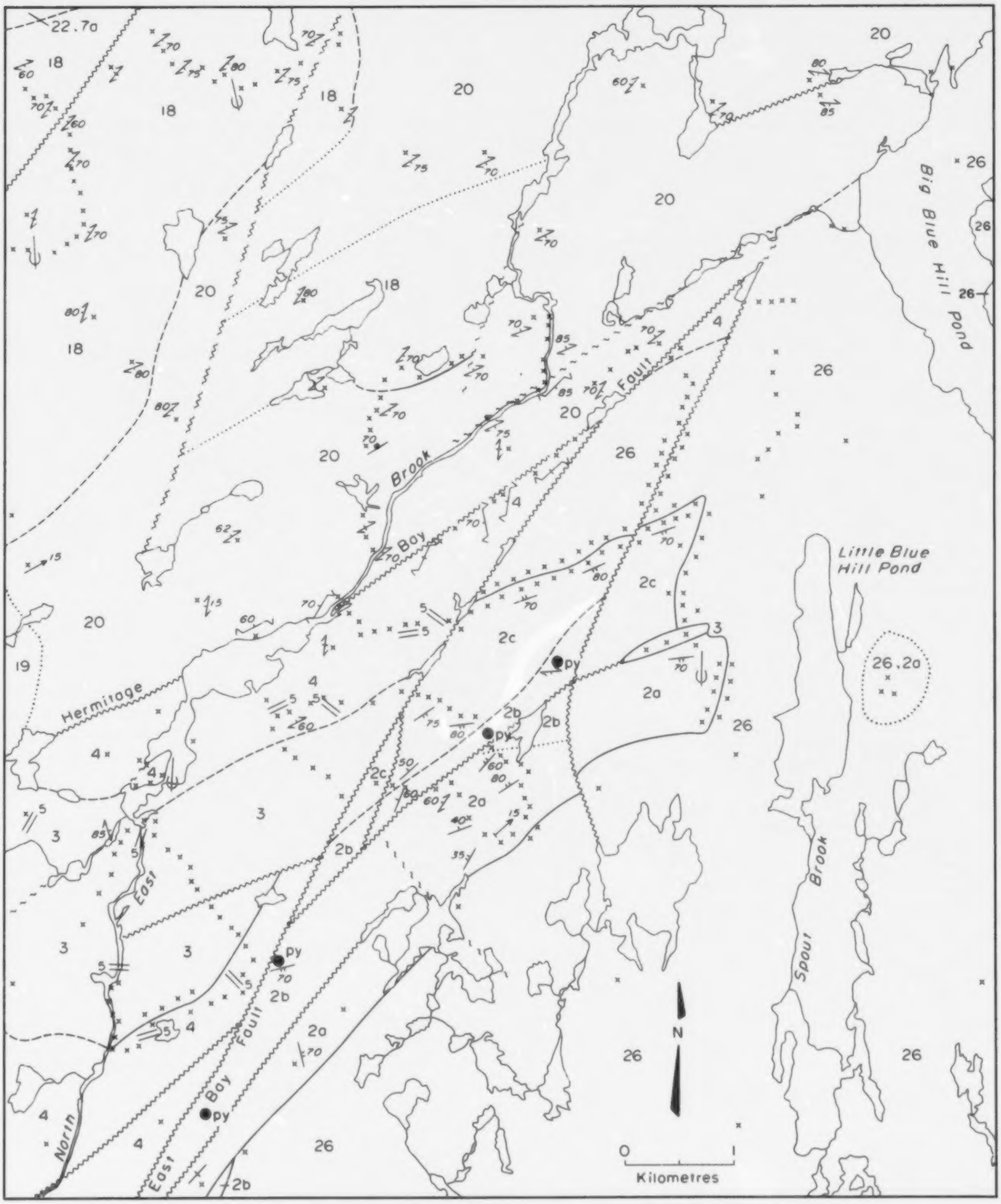

22.70
18
20
19
20
26
Big Blue Hill Pond
Little Blue Hill Pond
26,20
Hermitage
Bay
Brook
Fault
East
Bay
Fault
North
East
Spout
Brook
2a
2b
2c
3
4
py
N
0
1
Kilometres

Figure 2. *Geological map of the Rencontre Formation in the Big Blue Hill Pond area (from Dickson, 1987b); legend as in Figure 1.*

granitoid and metasedimentary rocks. Various phases of the Ackley Granite Suite were also outlined.

Fenton (1981a,b) reported on extensive geophysical, geochemical and geological surveys and prospecting carried out in the area between Little River and the eastern end of Kaegudeck Lake. West of Medonnegonix Lake, several geophysical conductors were mapped and trenched and found to be mainly graphitic horizons. However, pyrite–pyrrhotite mineralization was also discovered in bedrock and anomalous Zn and Sb values were obtained in soils at the 'Lulwind Cove' horizon, 2 km northwest of Medonnegonix Lake. Epidote ± carbonate alteration of mafic volcanic rocks at Lulwind Cove was also noted, but no significant gold values were obtained. It is perhaps significant that the highest Sb and Zn values (160 and 2040 g/t respectively) were obtained from rocks in the fault zone between chlorite schist and sedimentary rocks. This fault is termed the Le Pouvoir Fault in this report (see Figure 3).

Swinden (1980, 1982) presented a metallogenic model for the various mineral occurrences in the Bay d'Espoir area including the Hungry Grove Pond and Mount Sylvester map areas. Swinden (op. cit.) and Colman-Sadd (1980a) interpreted the volcanic rocks of the Isle Galet Formation as lateral facies variants of a volcanic complex, centred near Kim Lake (Mount Sylvester map area), with more distal facies now exposed to the southwest.

Vanderveer (1982) carried out a reconnaissance survey of glacial features in the Hungry Grove Pond map area as part of a regional survey of the southern half of the Ackley Granite.

Following the discovery of gold in the Ordovician rocks at Hope Brook, numerous companies staked the stratigraphically and laterally equivalent Isle Galet Formation (see O'Brien and Dickson, 1986). Tillicum Resources Limited and Westfield Minerals Limited hold the ground in the Hungry Grove Pond map area. Extensive till and soil geochemical surveys and prospecting (McHale, 1985a,b; McHale and McKillen, 1986) resulted in the rediscovery of the Le Pouvoir Sb showing (apparently discovered by P. Chance, see Fenton 1981b; McHale, 1985a) and the discovery of several areas with minor stibnite and anomalous gold values (McKillen, written communication to J. Tuach, 1986) in the Le Pouvoir horizon (McHale, 1985a; see Figure 3). Westfield Minerals (1986) reported high gold values in 'felsic volcanic tuffs' of the Isle Galet Formation (Little River prospect; see Figure 4). The '... mineralized zone ...' which occurs within a '... target stratigraphic horizon for 30 km' has been termed the Kim Lake horizon (McHale, 1985a) and extends through the northwest corner of the map area (see Figures 3 and 4).

Tuach (1984a,b) reported significant Sn and W values from greisen in the Ackley Granite Suite, southeast of Big Blue Hill Pond. Tuach *et al.* (1985) showed systematic differences in delta ^{18}O values for the Hungry Grove Granite (Unit 26), of the Ackley Granite Suite, and the Koskaecodde pluton. Higher values in the Koskaecodde pluton reflect input from the Gander Zone metasedimentary rocks and the lower values in the Ackley Granite Suite reflect input from the volcanic rocks and volcaniclastic sediments of the Avalon Zone. Tuach *et al.* (1986) and Tuach (1987) described certain geochemical trends in the Ackley Granite Suite that resulted from high-level enrichment processes in high-silica granites. Tuach (1987) named the various units of the Ackley Granite Suite and reported new ages for some units and mineralization in the suite. The ages for the various granites, along with the geochemical differences, indicate that the Koskaecodde pluton is unrelated to the Ackley Granite Suite.

Adjacent map areas have been mapped by Williams (1M/11, 1971), Colman-Sadd (1M/13, 1976), O'Brien *et al.* (1M/15, 1984) and Dickson (2D/3; 1986, 1987a). A summary of the regional geology and metallogenesis is found in Colman-Sadd and Swinden (1982).

Radiometric Dating

Wanless *et al.* (1972) obtained a 405 ± 17 Ma K/Ar (biotite) age (recalculated using current decay constants) on foliated granite (Unit 21, North West Brook Complex) near the southwest corner of Medonnegonix Lake. Tuach (1987) dated the Koskaecodde pluton (Unit 25) at 427 ± 12 Ma (Rb/Sr whole rock) and 410 ± 4 Ma (^{40}Ar/^{39}Ar biotite) and the granite in the Big Blue Hill Pond area (Unit 26) was dated at about 358 ± 12 Ma (Rb/Sr whole rock) and 367–372 Ma (^{40}Ar/^{39}Ar biotite and hornblende)

GENERAL GEOLOGY

Physiography and Glacial Features

The Hungry Grove Pond map area contains remnants of the 'High Valley Peneplane', which is estimated to have had an average height of 1000 feet in the Bay d'Espoir area (Twenhofel and McClintock, 1940). Remnants include 'Big Blue Hill' (1065 feet) and 'Red Cliff Pond hill' (925 feet); isolated hills west of Medonnegonix Lake and Western Pond are over 900 feet high. The Precambrian volcanic rocks south of Rally Pond form a coastal ridge that commonly exceeds 1000 feet in height. Most of the area forms part of the lower 'Lawrence Peneplane', which averages 700 feet in this area.

The topography reflects the variations in rock type such that low ground is underlain by homogeneous granites of the Koskaecodde pluton and the Ackley Granite Suite and is undulating, whereas the other areas comprising a great variety of rock types are highly dissected. Faults are commonly the sites of deep gorges.

The entire area was glaciated and striae and erratics are ubiquitous. Striae typically trend toward 170° with a range from 150° to 190°. Crag and tail, stoss and lee surfaces, and rock ramps also indicate a southerly ice-flow direction. Most of the area east of Medonnegonix Lake and Little Blue Hill Pond is hummocky terrain having innumerable granite erratics of local origin. Vanderveer (1982) noted abundant south-oriented drumlinoid linear moraines and minor transverse moraines in this area. The area to the west is dominated by

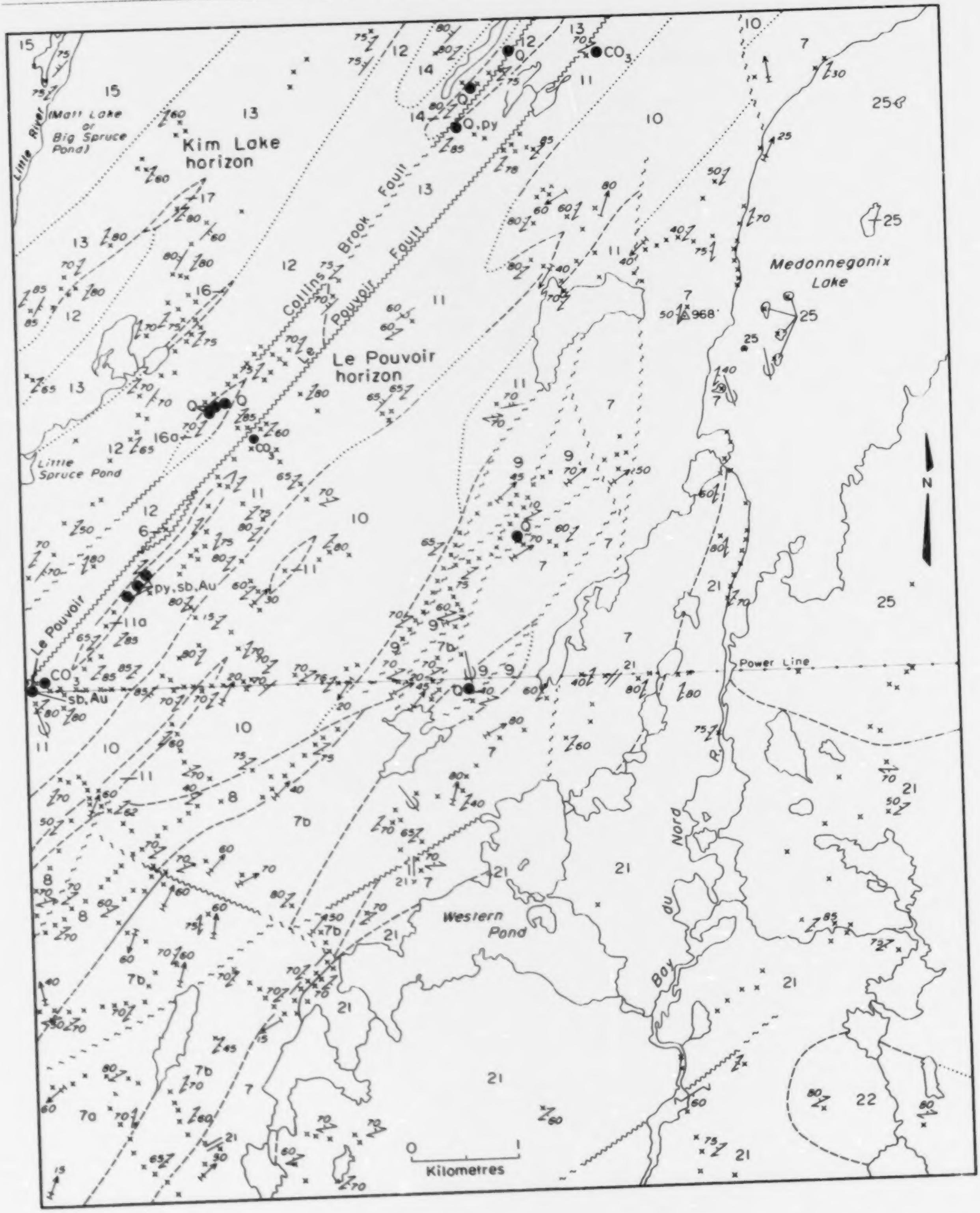

Little River
Malt Lake or Big Spruce Pond
Kim Lake horizon
Collins Brook Fault
Pouvoir Fault
Le Pouvoir horizon
Le Pouvoir
Little Spruce Pond
Medonnegonix Lake
Power Line
Bay du Nord R.
Western Pond
968
Q
Q,py
CO3
py,sb,Au
sb,Au
N
0
1
Kilometres
7
7b
8
9
10
11
12
13
14
15
16
21
22
25

Figure 3. *Geological map of the Baie d'Espoir Group, west of Medonnegonix Lake (from Dickson, 1987b); legend as in Figure 1.*

exposed rock, and till is restricted to the valleys. Boulder fields are locally extensive. Twelve km south-southeast of Medonnegonix Lake, rounded boulders (up to 5 m) of serpentinized peridotite and harzburgite occur in a lateral moraine along with biotite schist of local derivation. The closest known source of serpentinized ultramafic rock is 5 km northeast of Conne River Pond (Mount Sylvester map area; Dickson, 1987) suggesting that they have been transported approximately 30 km. Two eskers occur in the northern part of the map area and indicate that meltwater channels drained to the south to the South East Brook and Mal Bay Brook drainage systems.

Drainage patterns partly reflect the geological structures with faults often utilized by streams. Stream capture is particularly well displayed in the vicinity of the Hermitage Bay Fault and several major rivers that cross the fault have captured the subsequent streams that flow along the fault line. Major rivers such as the Bay du Nord River, North East and North West brooks, may have originally flowed along parts of the Hermitage Bay Fault valley. The river valleys have been modified by ice as truncated spurs occur along the major rivers.

AVALON ZONE

Long Harbour Group (Units 1 and 2)

The Belle Bay Formation (White, 1939; Williams, 1971) is the oldest formation of the Long Harbour Group (Williams, 1971) and the Rencontre Formation (White, 1939) is the youngest (Williams, 1971). South of the map area, the Belle Bay Formation is unconformably overlain by the Rencontre Formation and the fossiliferous, Middle Cambrian Youngs Cove Group (Smith and White, 1954; Williams, 1971).

The Belle Bay Formation (Unit 1) forms a protrusion from the main belt of volcanic rocks to the south of the map area. The contact with the Ackley Granite Suite was mapped and described by Dickson (1982), who noted contact-metamorphic andalusite porphyroblasts and recrystallization of the rocks along the contact. The dominant rock types in this area are weakly cleaved, grey rhyolite, rhyolitic lapilli tuff, tuffaceous sandstone and crystal-lithic tuff. Flow layering is locally developed in the rhyolite. Near the contact with the Ackley Granite Suite, 3 km southeast of Rally Pond, thick basalt flows are intercalated with the tuffs. Bedding is apparent only in the tuffaceous sandstones and is generally parallel to the northeast-striking cleavage that dips to the northwest or southeast.

The Rencontre Formation (Unit 2), exposed along a highly dissected, northeast-trending narrow ridge, can be divided into three components (Figure 2) which, based on the few facing criteria and the north dip of the beds, young from south to north. The oldest component (subunit 2a) is a sequence of mainly very thick bedded (up to 5 m), virtually featureless, grey sandstone with locally abundant muscovite. Parallel laminations in the thick bedded sandstones have been enhanced by the growth of mica during contact metamorphism. Strongly cleaved, thinner bedded (up to 1 m), grey sandstone is locally pyritic with rusty weathering surfaces.

Subunit 2b is dominated by thin bedded (2 to 10 cm), strongly cleaved, grey, locally micaceous sandstone and siltstone. A prominent feature of the subunit is the extensive gossans formed by weathering of fine grained disseminated pyrite. The siltstones locally contain cordierite porphyroblasts 1 km from the surface contact with the Ackley Granite Suite. This may indicate that the Rencontre Formation is a roof pendant of the granite as cordierite porphyroblasts are commonly restricted to the area adjacent to the contact with the granite.

Subunit 2c contains a variety of sedimentary rock types such as breccia, conglomerate, sandstone and limestone. Of particular interest are the grey and red, medium to thick bedded, clast-supported, pebble conglomerate and breccia that contain abundant felsic and mafic volcanic clasts (Plate 1). The volcanic clasts are probably from the Belle Bay Formation. The conglomerate is interbedded with grey, locally micaceous sandstone which, as in the conglomerates, contain abundant feldspar and quartz grains. Cross bedding was found in a few places. Near the northern contact of the subunit with the Ackley Granite Suite, 1 to 3 cm long, angular, sedimentary clasts occur in thick-bedded breccia. A thin, lensoid (20 m by 5 m) sequence of limestone and calcareous siltstone is interbedded with the conglomerate and sandstone.

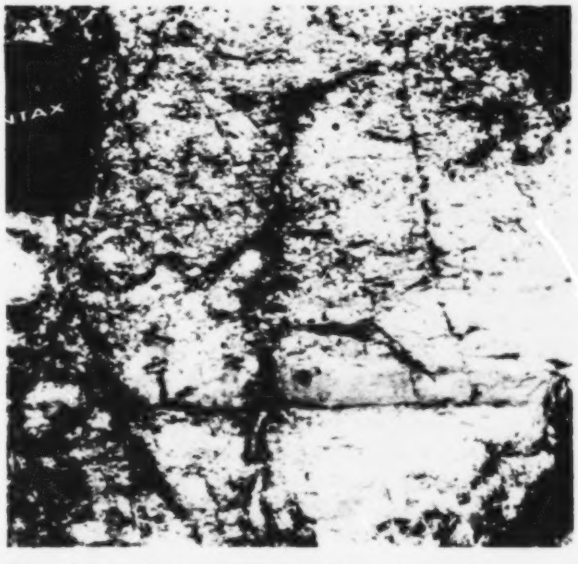


Plate 1. *Bedded breccia (subunit 2c), from the Rencontre Formation, showing rhyolite (white) and sedimentary (grey) angular clasts; at contact with Ackley Granite, 2 km southeast of South East Brook; lens cap is 5 cm in diameter.*

Parallel laminations and bedding, cross bedding, poor sorting and angular fragments suggest that the Rencontre Formation is a fluvial sequence. The limestone may indicate a marine component in the sequence.

The formation is in contact with the Simmons Brook Batholith along the East Bay Fault (Williams, 1971) to the west, and is in intrusive contact with the Ackley Granite Suite to the north, east and southeast. The fault contact with the Simmons Brook Batholith is exposed south of the map area (Williams, 1971). In several places, however, the Rencontre Formation and the Simmons Brook Batholith are brecciated and cut by small quartz veins, and a major northeast-trending lineament defines the trace of the East Bay Fault. There is no evidence that the Simmons Brook Batholith has intruded the Rencontre Formation. The intrusive contact of the Ackley Granite Suite is generally sharp and parallel to the strike of the Rencontre Formation. However, a 200 to 300 m wide zone of intrusion breccia has developed where the Ackley Granite Suite cuts across the strike of the Rencontre Formation, to the west of Little Blue Hill Pond. A well-developed aureole is indicated by randomly orientated biotite and muscovite porphyroblasts in a hornfels zone up to 300 m wide.

Simmons Brook Batholith (Units 3–5)

The northeastern 60 km² portion of the 150 km² Simmons Brook Batholith (Williams, 1971; Bay du Nord Batholith of White, 1939) is exposed in the map area. Massive gabbro (Unit 3) and granodiorite (Unit 4) are the main components of the Simmons Brook Batholith; diabase dykes (Unit 5) cut Units 3 and 4. The contact of the gabbro with the granodiorite is sharp in an exposure on South East Brook. Williams (1971, page 18) notes that mafic phases occur as inclusions within the granitic rocks. In other areas, gabbro to granodiorite are in close proximity (5 m) but contacts are not exposed.

The gabbro is commonly medium to coarse grained, equigranular, massive, green to black, and contains pyroxene, hornblende and dark-coloured plagioclase (Plate 2). Locally the gabbro is a coarse grained hornblendite and in other places a medium grained diabase. Epidote is common along joints and in narrow, fault breccia zones. Along the northern contact with the granodiorite, the gabbro contains abundant (30 percent), 1 cm long hornblende laths in a plagioclase-rich matrix. This zone may represent a transitional contact with the granodiorite.

The granodiorite is a massive, green to buff, quartz–plagioclase–hornblende–biotite rock with about 10 percent K-feldspar. Hornblende forms stubby, 5-mm-long laths. Although the granodiorite is dominantly coarse grained (average 5-mm crystals), medium grained, granodiorite is the typical lithology near the contact with the gabbro on South East Brook. The granodiorite is altered and brecciated along the Hermitage Bay Fault and veined by quartz. The mafic minerals have been altered to sericite and chlorite.

Diabase (Unit 5) occurs throughout the batholith as isolated dykes that have no consistent trend. Crosscutting dykes indicate that at least two generations are present. The most common variety of diabase is medium grained (Plate 2) and massive whereas fine grained hornblende-porphyritic diabase is less common. The dykes are commonly altered with epidote and chlorite-coated joint surfaces and rare quartz veins. Along the Hermitage Bay Fault, northeast of North East Brook, brecciated diabase is common within the highly brecciated and chloritized granodiorite of the Simmons Brook Batholith.

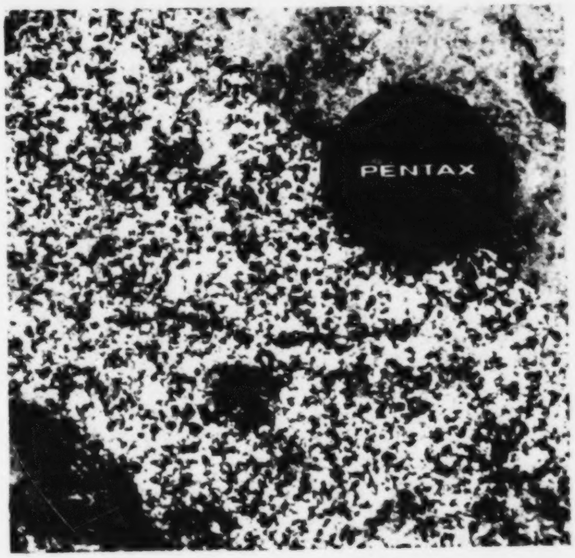


Plate 2. *Gabbro (Unit 3) (below lens cap) cut by grey, fine grained diabase dyke (above lens cap) (Unit 5), both part of the Simmons Brook Batholith; on South East Brook–lens cap is 5 cm in diameter.*

The Simmons Brook Batholith forms a fault-bounded block between the East Bay and Hermitage Bay Faults. Southwest of the Hungry Grove Pond map area, the batholith has intruded the upper Precambrian Connaigre Bay Group (Widmer, 1950), which is a probable stratigraphic equivalent of the Long Harbour Group. O'Driscoll (1977) and O'Driscoll and Strong (1979) demonstrated a chemical similarity between the various units of the batholith and the volcanic rocks of the Connaigre Bay Group. They proposed that they were genetically related and therefore the same age, viz. late Precambrian. A gabbro dyke has intruded the Rencontre Formation, west of Little Blue Hill Pond, and a plug of gabbro has intruded the Belle Bay Formation, southeast of Rally Pond. These intrusions are assumed to be related to the Simmons Brook Batholith.

DUNNAGE ZONE

The Dunnage Zone is represented by the Middle Ordovician and/or older Baie d'Espoir Group (Units 7–15) that has been intruded by the Silurian and older North West Brook Complex (Units 18–23) and the Lower Devonian Koskaecodde pluton (Unit 25). Minor components are magnesite (Unit 6), gabbro (Unit 16), quartz veins (subunit 16a), granodiorite (Unit 17) and diabase (Unit 24). The Ackley Granite Suite is not restricted to this terrane but is described in this section.

Two major northeast-trending faults, which lie within the Isle Galet Formation, were discovered during this survey. The Le Pouvoir Fault is named after the Le Pouvoir Sb showing that lies 200 m southeast of the fault. The Collins Brook Fault, named after Collins Brook (in the St. Alban's map area), runs parallel and 500 m to the northwest of the Le Pouvoir Fault. Both faults are marked by prominant lineaments. A small exposure of magnesite, several areas of quartz–carbonate veins and fault breccia occur along the Le Pouvoir Fault. Large (<50 m) quartz veins occur along the Collins Brook Fault and in the adjacent sedimentary and volcanic rocks.

Magnesite (Unit 6)

The oldest component of the Dunnage Zone is considered here to be a small area of magnesite that outcrops along the Le Pouvoir Fault, 2 km northeast of the Le Pouvoir Sb–Au showing (Figure 3; Plate 3). This unit is considered to be older than the Baie d'Espoir Group as probable equivalent-aged ultramafics, in the Gander area, are nonconformably overlain by conglomerates and late Llanvirn–early Llandeilo fossiliferous calc-arenites of the Davidsville Group (Blackwood, 1978; Stouge, 1980). The Davidsville Group is interpreted as a lateral equivalent of the Baie d'Espoir Group (Blackwood and Green, 1983).

The magnesite occurs in a single exposure, along the lineament formed by the Le Pouvoir Fault, at the northeast corner of an elongate, 200-m-long pond. The exposure covers an area of about 50 m^2 and is surrounded by boulders of magnesite. The magnesite is a yellow-brown-weathering (grey on fresh surfaces) massive rock, veined by magnetite and carbonate. The magnesite is well jointed and unfoliated (Plate 3). Contacts with the surrounding rocks are not exposed. Analyses of two samples of magnesite give high Ni and Cr values (Table 1) and indicate an ultramafic parentage for the magnesite.

Table 1. Ni and Cr analyses (in g/t) for samples of magnesite (Unit 6) from the Le Pouvoir Fault

Sample No.	Ni	Cr
2242933	1780	1340
2242943	1370	1210

The presence of ultramafic rocks along the Le Pouvoir Fault may indicate that it is a deep-seated thrust that has penetrated oceanic crust forming the basement to the Baie d'Espoir Group (as postulated by Colman-Sadd, 1980a).

Baie D'Espoir Group (Units 7–15)

The Baie d'Espoir Group, as currently defined (Colman-Sadd, 1976), consists of the Salmon River Dam Formation, which is overlain from northwest to southeast by the North Steady Pond, St. Joseph's Cove, Riches Island and Isle Galet formations. Middle Ordovician fossils have been found in the Riches Island Formation. Colman-Sadd (1976) and Dunlop (1954) found poorly preserved fossils in the Riches Island and Isle Galet formations, which gave a poorly defined Ordovician to possibly Cambrian age. The Little Passage Gneiss (Colman-Sadd, 1974) have been interpreted to underlie the Baie d'Espoir Group and to be in thrust contact with the Isle Galet Formation (Colman-Sadd, 1976). A tentative Precambrian age was assigned to the gneisses (Colman-Sadd, 1974, 1976, 1980a). The thrust contacts between the Little Passage Gneiss and Isle Galet Formation are exposed along the Harbour Breton road (Figure 4). Continuous sections in the Western Pond area (Figure 3) indicate that the gneisses do stratigraphically underlie the Baie d'Espoir Group, although faulted and sheared contacts are also present. Thus the Little Passage Gneiss is here considered to be a lower unit of the group. Blackwood (1985) proposed that the Little Passage Gneiss also forms part of the Baie d'Espoir Group but occurs stratigraphically higher in the sequence on the overturned limb of a recumbent fold. The Salmon River Dam, North Steady Pond, and St. Joseph's Cove formations lie to the northwest of the map area and are described in some detail in Colman-Sadd (1976, 1980b) and Dickson (1987a).

Plate 3. *Massive, jointed magnesite (Unit 6) exposed along the Le Pouvoir Fault, 2 km northeast of the Le Pouvoir stibnite–gold showing; Barry Wheaton for scale.*

Rocks assigned to the Little Passage Gneiss occur in two areas. In the Western Pond–Medonnegonix Lake area, a complex belt of psammitic, semipelitic and pelitic schist, gneiss and migmatite (Unit 7, subunits 7a, 7b) occurs between the Isle Galet Formation and the North West Brook Complex. Dickson (1987a) indicated that this belt of metasedimentary rocks was a lower member of the Isle Galet Formation with no break in the sequence. A northeast-trending belt of biotite schist (Subunit 7a) lies within the North West Brook Complex and is continuous with previously defined Little Passage Gneiss to the west of the map area (Colman-Sadd, 1976).

The Little Passage Gneiss (Unit 7) consists mainly of strongly foliated and highly folded psammitic schist and gneiss (Plate 4). Toward the contact with Unit 21 granite, the metasedimentary rocks become migmatitic and are locally intruded by dykes of Unit 21. Along the western shore of Medonnegonix Lake, the metasediments display a well-developed banding which is probably related to recrystallization of thin beds within the aureole of the Koskaecodde pluton. To the southwest of Western Pond, the metasediments are cut by numerous quartz and pegmatite veins.

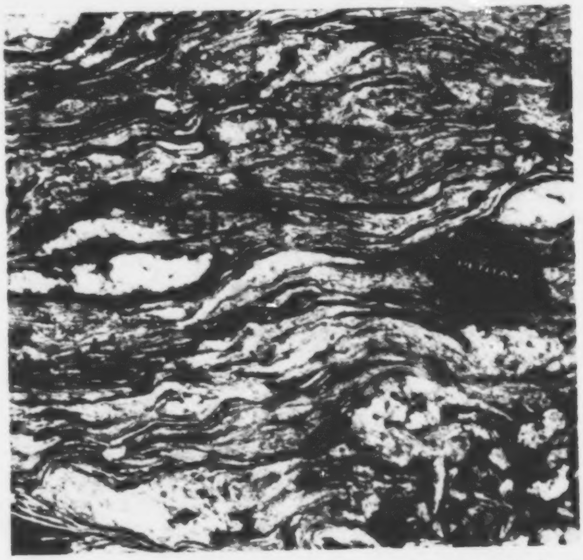


Plate 4. *Banded, biotite psammite gneiss (Unit 7; Little Passage Gneiss) with lensoid, quartz segregations in the aureole of the North West Brook Complex; on power line, 600 m west of contact with Unit 21—lens cap is 5 cm in diameter.*

Subunit 7a of the Little Passage Gneiss is predominantly biotite-rich, pelitic schist with lesser psammitic schist. In the southern outcrop area, numerous granite dykes occur along the margin of the subunit. Subunit 7b is dominated by psammitic schist with minor, interbedded, pelitic and semipelitic schist. Some psammite beds are highly porous, rusty weathering, and veined by quartz, and originally may have been felsic volcanic rocks.

Isle Galet Formation (Units 8–13). A variety of sedimentary, felsic and mafic volcanic rocks comprise the Isle Galet Formation. One cross-laminated, northwest-

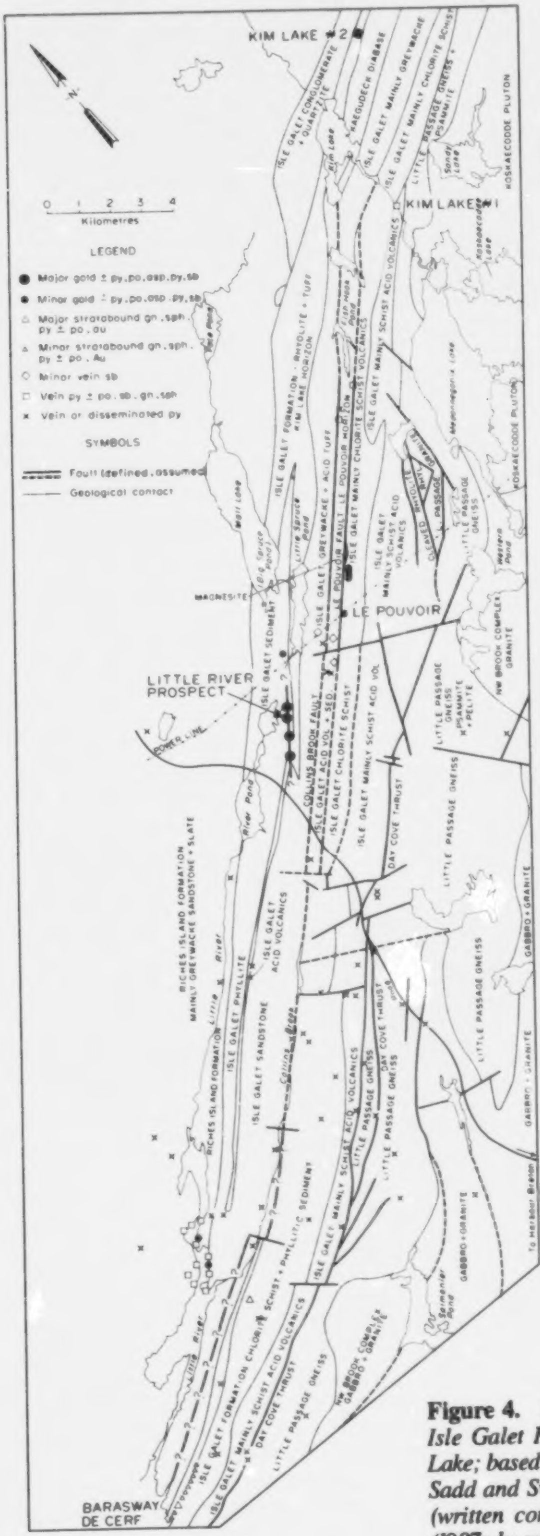

N
0 1 2 3 4
Kilometres
LEGEND
● Major gold ± py.po.asp.py.sb
● Minor gold ± py.po.asp.py.sb
△ Major stratabound gn.sph.py ± po.au
▲ Minor stratabound gn.sph.py ± po.Au
○ Minor vein sb
□ Vein py ± po.sb.gn.sph
× Vein or disseminated py
SYMBOLS
Fault (defined, assumed)
Geological contact
KIM LAKE #2
KIM LAKE #1
LE POUVOIR
LITTLE RIVER PROSPECT
BARASWAY DE CERF
MAGNESITE
POWER LINE
ISLE GALET CONGLOMERATE + QUARTZITE
KAEGUDECK DIABASE
ISLE GALET MAINLY GREYWACKE
ISLE GALET MAINLY CHLORITE SCHIST
LITTLE PASSAGE GNEISS PSAMMITE
KOSKAECODDE PLUTON
ISLE GALET FORMATION - RHYOLITE + TUFF
KIM LAKE HORIZON
ISLE GALET MAINLY SCHIST ACID VOLCANICS
LE POUVOIR HORIZON
LE POUVOIR FAULT
ISLE GALET GREYWACKE + ACID TUFF
CLEAVED RHYOLITE
PASSAGE
LITTLE PASSAGE GNEISS
ISLE GALET SEDIMENT
COLLINS BROOK FAULT
ISLE GALET ACID VOL + SED
ISLE GALET CHLORITE SCHIST
ISLE GALET MAINLY SCHIST ACID VOL
LITTLE PASSAGE GNEISS PSAMMITE + PELITE
NW BROOK COMPLEX GRANITE
DAY COVE THRUST
RICHES ISLAND FORMATION MAINLY GREYWACKE SANDSTONE + SLATE
ISLE GALET PHYLLITE
ISLE GALET SANDSTONE
ISLE GALET ACID VOLCANICS
GABBRO + GRANITE
ISLE GALET PHYLLITIC SEDIMENT
ISLE GALET FORMATION CHLORITE SCHIST + PHYLLITE
ISLE GALET MAINLY SCHIST ACID VOLCANICS
NW BROOK COMPLEX GABBRO + GRANITE
Little River
Collins Brook
River Pond
Medonnegonix Lake
Western Pond
Kim Lake
Big Spruce Pond
Little Spruce Pond
Saimonier Pond
To Harbour Breton

Figure 4. *Simplified geological–metallogenic map of the Isle Galet Formation between Barasway de Cerf and Kim Lake; based on Dunlop (1954), Colman-Sadd (1976), Colman-Sadd and Swinden (1982), Swinden (1980, 1982), McKillen (written communication to J. Tuach, 1986), and Dickson (1987a,b; unpublished data).*

dipping, overturned sandstone bed was found in Unit 11 but some found in the Mount Sylvester map area (Dickson, 1987a) indicate that the formation youngs to the northwest. Units form linear belts along strike with no apparent major folds. Thus the sequence is assumed to face to the west toward the less deformed rocks. However, the newly-discovered, strike-parallel Le Pouvoir Fault defines significant abrupt changes in deformation and rock type which, along with small tight folding, indicate that the stratigraphic sequence is more complicated.

Unit 8 pelite and psammite is in gradational contact with subunit 7b. These black and grey rocks form thick sequences that lack sedimentary structures. Bedding is apparent only where pelite and psammite are present. The pelites show widespread development of folded cleavage and late quartz veining. Fold axes of the small folds commonly plunge to the northeast at 50 to 70° and the quartz veins locally cut across the fold axes. The veins are, however, more commonly parallel to the cleavage. Rusty zones occur within the pelites and one pyritic zone was trenched by Hudson's Bay Oil and Gas Limited (Fenton, 1981a) but no significant mineralization was found.

Unit 9 consists of cleaved and locally folded, pink to grey rhyolite and rhyolitic tuff exposed in two areas. The contact between Unit 9 and the Little Passage Gneiss is locally a zone of intense deformation, and in one place the rhyolite has been extensively silicified and then deformed along the contact (Plate 5). Narrow mylonite zones (10 to 50 m) occur within the Little Passage Gneiss close to the contact. At the power line, west of Medonnegonix Lake, the southern area of rhyolite is rusty and quartz veined and is probably in fault contact with the Little Passage Gneiss as topographic lineaments surround the block of rhyolite.

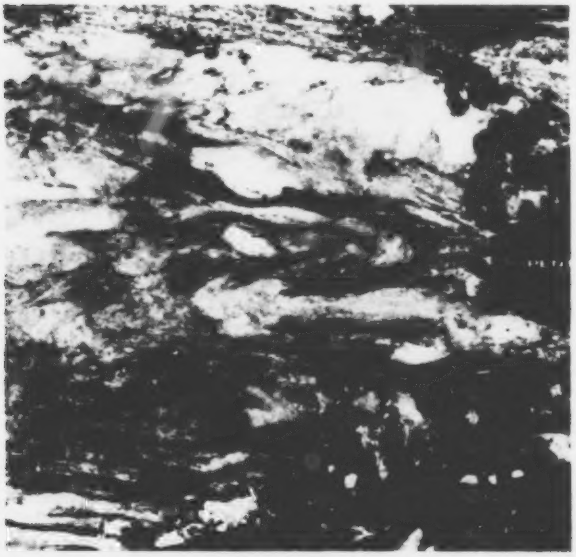


Plate 5. *Folded quartz veins, in silicified rhyolite (Unit 9) of the Isle Galet Formation, along the fault contact of the formation with the Little Passage Gneiss, 2 km west of Medonnegonix Lake; lens cap is 5 cm in diameter.*

Unit 10 consists of an apparently thick sequence of cream to buff-coloured, quartz–sericite schist, cleaved and recrystallized, rhyolitic tuff, and minor chlorite–sericite schist and pelitic schist. Volcanic textures are locally preserved and the rock is derived from a crystal tuff with quartz and feldspar phenocrysts. Elongate, darker-coloured fragments are rarely present and these may be fiamme or coarse ejecta in the tuff. The rhyolite and rhyolitic tuff are generally less schistose toward the contact with Unit 9 and the rhyolite has been recrystallized to form granoblastic aggregates of quartz, feldspar and sericite.

The tuffs (Unit 10) have their widest areal extent in the vicinity of the power line and the unit tapers to the northeast and southwest. There is little change in rock type along strike. Northwest of Medonnegonix Lake, the tuffs are interbedded with chlorite schists and pelites. Colman-Sadd (1976) has shown that the schistose, felsic volcanic rocks south of the Collins Brook Fault extend to the southwest in a 1-km-wide zone to Barasway de Cerf (Figure 4).

Unit 11 is dominated by chlorite schists with minor interbedded, weakly cleaved, basalt flows and quartz–sericite schist. Psammitic and pelitic schist (subunit 11a) occur within Unit 11. This assemblage has been informally termed the Le Pouvoir horizon (McHale, 1985a). The Le Pouvoir horizon is separated from Units 12 and 13 by the Le Pouvoir Fault. The chlorite schists are dominantly green to buff and homogeneous, so that bedding is rarely apparent. Primary layering was observed only where psammites or quartz–sericite schists are interbedded with the tuffs. The chlorite schists contain euhedral plagioclase phenoclasts and are considered to be derived from mafic tuffs. Two km northeast of Le Pouvoir, a 75-m-thick, weakly cleaved, basalt flow is intercalated with the sequence. Generally, the sedimentary units are less than 100 m thick and form elongate lenses within the sequence of chlorite schists.

Alteration of the sequence is concentrated along the western margin of the Le Pouvoir horizon. At the Le Pouvoir showing, a 2-m-thick, cream-coloured band, within the chlorite schist unit, contains abundant interstitial carbonate and disseminated pyrite and in several places to the northeast of Le Pouvoir, the chlorite schist is veined by quartz and carbonate. In several places close to the fault, a banded, highly folded rock with chlorite-rich and quartz–sericite-rich, 1-cm-thick layers locally contains carbonate and quartz veins (Plate 6). The banded unit is possibly a recrystallized chemical sediment. A similar banded rock occurs 1.7 km west of Medonnegonix Lake. Fenton (1981b) noted that carbonate–epidote alteration occurs along the 'Lulwind Cove horizon' that lies along the Le Pouvoir Fault.

Unit 12 of the Isle Galet Formation is interbedded with the felsic volcanic rocks of Unit 13 and pebble conglomerate of Unit 14. Collectively, these three units form the Kim Lake horizon. The Collins Brook Fault occurs within Unit 12 and

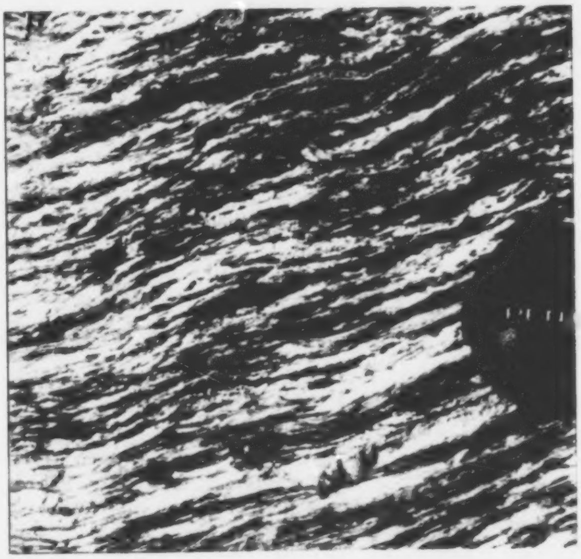


Plate 6. *Banded quartz–carbonate–sericite and chlorite–sericite schist (part of Unit 11 of the Isle Galet Formation), 2 km northeast of the Le Pouvoir stibnite–gold showing; lens cap is 5 cm in diameter.*

is locally marked by extensive quartz veins (in part subunit 16a). Sheared and brecciated sedimentary and volcanic rocks (eastern belt of Unit 13) occur along the northern portion of the fault. The fault may continue southwest of the map area to Baraswav de Cerf area (Figure 4).

Unit 12 consists of medium bedded, well cleaved, grey sandstone and siltstone. Sedimentary features are rare and consist of parallel laminations. No younging criteria were found. This lack of younging criteria is particularly frustrating as the bifurcation of Unit 13 around a wedge of Unit 12 sediments could indicate tight folding. It is assumed that this wedge is simply a lens of sediments deposited within the sequence of volcanics and indicates that sedimentation and volcanism were contemporaneous. The sediments are steeply dipping and the main (first) cleavage is parallel to bedding. Second-generation folds are open, gently northeast-plunging and have axial planes and associated cleavage that dip to the southeast at around 10°.

Unit 13 consists of two areas of medium to very thick bedded, felsic volcanic rocks and minor, thin to thick bedded, clastic, sedimentary rocks. The southeastern area lies between the Collins Brook and Le Pouvoir faults and is underlain by massive rhyolite, interbedded, schistose felsic and possibly mafic (chloritic) tuff and minor, fine grained porcellanite (waterlain, siliceous, volcanic ash). Extensive, rusty, quartz veins cut the porcellanite near the Collins Brook Fault. The northwestern belt of Unit 13, forming the Kim Lake horizon, is dominated by a central portion of cleaved, fine grained, rhyolitic tuff. The southeastern portion of this belt consists of interbedded fine grained tuff, lapilli tuff, and rhyolite exposed in a series of low hills. The northwestern portion of the belt contains quartz–feldspar-crystal tuff and fine grained tuff.

In the Mount Sylvester map area, the volcanic rocks of Unit 13 narrow to about 500 m and are dominated by massive rhyolite and autobrecciated rhyolite. These types of felsic volcanics are commonly considered to be proximal deposits whereas the bedded tuffs and ash flows (such as the crystal tuffs) may be deposited well away from a volcanic centre. A thin unit of felsic volcanic rocks, continuous with the Kim Lake horizon, has been traced to 8 km northeast of Barasway de Cerf (Colman-Sadd, 1976; Figure 4). These features support the proposal of Swinden (1980) that the volcanic centre was in the Kim Lake area. Furthermore, the volcanic rocks appear to have been deposited only to the southwest of the Kim Lake area and this may indicate some topographic control on deposition of the flows.

Unit 14 consists of pebble conglomerate, breccia and coarse micaceous sandstone outcropping in two separate areas. The southeastern area lies to the northwest of the Collins Brook Fault and consists of schistose, extensively quartz veined, pebble conglomerate with abundant pebbles of felsic volcanic rocks. The pebbles contain the same schistosity as the matrix. The northwestern area of Unit 14 consists of thick breccia beds, with angular fragments of rhyolite and sandstone, interbedded with grey muscovite-rich sandstone and pelite. The beds range in thickness from a few centimetres to about 2 m.

Riches Island Formation (Unit 15). In the map area, the Riches Island Formation is a poorly exposed sequence of medium bedded, grey sandstone and siltstone, and is exposed on islands in Little River (Figure 3). The sediments consist of parallel-bedded, thinly laminated greywacke and siltstone containing a well-developed cleavage parallel to bedding. Contacts with the presumably underlying Isle Galet Formation are not exposed in the map area. Colman-Sadd (1976) reported that a conformable contact is exposed near Morgan Arm, in Bay d'Espoir.

Units 16, 16a, and 17: Gabbro, quartz veins, and granodiorite

A 5-m-thick, weakly cleaved, medium grained, equigranular, gabbro dyke (Unit 16) has been intruded parallel to the contact between Unit 12 sediments and Unit 13 felsic volcanic rocks. This dyke has an exposed length of about 30 m and is similar to the Kaegudeck diabase dykes in the Kim Lake area (Dickson, 1987a). A 5-m-thick, chloritic pelite band lies between the dyke and the felsic volcanic rocks.

Subunit 16a is a series of extensive outcrops of quartz veins that occur along the Collins Brook Fault. The veins are discontinuously exposed over a distance of 500 m along strike and the unit has an apparent width of 100 m. Quartz veins within Units 12, 13 and 14 are part of the same system. The veins are composite with late, massive, quartz veins injected into foliated vein quartz.

Unit 17 is a poorly exposed, white-weathering, quartz–feldspar-porphyritic (?)granodiorite cut by narrow shear zones. On fresh surfaces the rock is black and fine grained and may be mylonitic.

North West Brook Complex (Units 18–23)

A variety of foliated, biotite ± muscovite granitoids and spatially associated metasedimentary rocks of the Little Passage Gneiss comprise the North West Brook Complex (Dickson, 1983). Exposed contacts show that the granitoids have intruded the Little Passage Gneiss and have been intruded by the Ackley Granite Suite. Although the contact with the massive Koskaecodde pluton is not exposed, a well-defined aeromagnetic anomaly coincides with the change from massive to foliated granitoids and the contact is almost certainly intrusive.

The oldest unit of the North West Brook Complex is mafic, coarse grained, feldspar-porphyritic, strongly foliated, biotite granodiorite and granite (Unit 18; Plate 7). This unit commonly contains xenoliths of metasediment of the Little Passage Gneiss and is cut by dykes of adjacent intrusions. Xenoliths of Unit 18 occur in Units 19, 20 and 23. The feldspar phenocrysts in Unit 18 are deformed and form augen. Near the contact with the Ackley Granite Suite, mafic, massive quartz diorite (subunit 18a) is tentatively included with Unit 18. The granodiorite is similar to the Gaultois Granite of Colman-Sadd (1974).

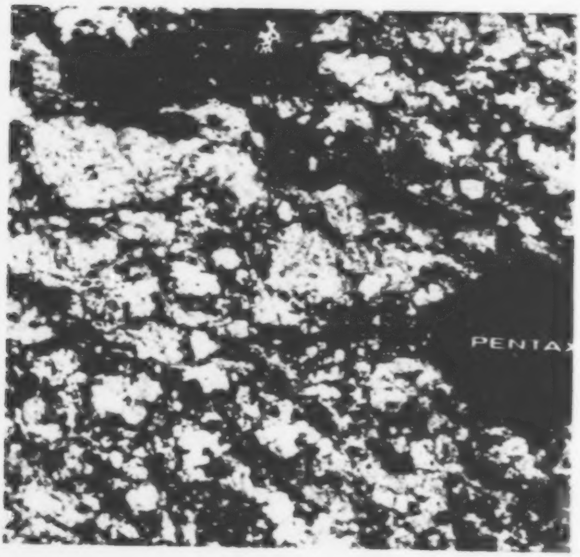


Plate 7. *Coarse grained, K-feldspar-porphyritic, foliated, biotite granite (Unit 18) of the North West Brook Complex; 4 km north of Big Blue Hill Pond–lens cap is 5 cm in diameter.*

Units 19 and 20 are medium grained, equigranular granites with Unit 19 being more mafic and lacking muscovite. Foliations are generally weak and only along the Hermitage Bay Fault is Unit 20 strongly deformed. The rock is foliated and brecciated having fragments coated with sericite and chlorite. Quartz veins are common. Unit 21 consists of variably deformed, coarse grained, K-feldspar porphyritic biotite granite and is most commonly weakly deformed. Locally, however, narrow (5 to 20 m) zones contain intensely deformed granite but these do not extend over 100 m in length. Near the contact with the Koskaecodde pluton, Unit 21 is locally massive and difficult to distinguish from the Koskaecodde pluton. However, the presence of medium grained, muscovite-bearing granite dykes (Unit 22) can be used to differentiate the two granites.

Unit 22 consists of a number of slightly different types of granite. Various combinations of biotite ± muscovite ± feldspar phenocrysts occur over short distances and mappable units are therefore difficult to define. In the vicinity of the Bay du Nord River, granite with 2 cm by 3 mm, rectangular, K-feldspar phenocrysts are common. This granite is cut by large dykes of equigranular granite. Unit 23 is a distinctive, pink, fine grained, biotite granite, which has been emplaced in that part of the Little Passage Gneiss enclosed within the complex. This granite has not been intruded by any other granite and is considered to be the youngest member of the complex.

Pegmatites are common within the muscovite-bearing Units 20 and 22 of the complex, particularly in the vicinity of the metasediments (subunit 7a) and near the contacts with Unit 18. Beryl was found in one pegmatite (Dickson, 1983).

Diabase Dykes (Unit 24)

A few isolated diabase dykes have intruded the North West Brook Complex and the Little Passage Gneiss. All are fresh, massive, parallel-sided, and display chilled margins. The dykes range in width from 1 to 4 m, are steeply dipping and trend north or northeast. The presence of only one diabase dyke in the Koskaecodde pluton and the Ackley Granite Suite (Dickson, 1983) indicates that the more abundant dykes in the North West Brook Complex predate these units.

Koskaecodde Pluton (Unit 25)

The Koskaecodde pluton (Tuach, 1987) is an undeformed, K-feldspar-porphyritic, biotite granite that has intruded the Little Passage Gneiss and the North West Brook Complex. On the southwest shore of Medonnegonix Lake, an intrusive breccia is formed by blocks of psammitic, gneissic hornfels in a granite matrix. North of Red Cliff Pond, the granite of Koskaecodde pluton is distinctly grey rather than buff or pink. This may reflect alteration or contact metamorphism by the Ackley Granite Suite.

The Koskaecodde pluton consists of coarse grained, K-feldspar-porphyritic biotite granite with 10 to 30 percent phenocrysts and 2 to 5 percent coarse (2 to 5 mm) biotite flakes. Rare, thin, layered granite dykes contain well-aligned biotite in a hypidiomorphic-granular matrix; this alignment is considered to be flow layering.

Ackley Granite Suite (Units 26 and 27)

The western portion of the Ackley Granite Suite and its contact with the North West Brook Complex were mapped in detail. The intrusive contact with the complex is exposed in one place and is discordant to the foliation in Unit 18 of the complex. The contact was found to be several kilometers farther west from that shown by Dickson (1983). The Ackley Granite Suite is generally coarse grained up to the contact. Fine grained, quartz–feldspar-porphyry dykes, typical of the marginal facies of the Ackley Granite Suite, occur in coarse, variably porphyritic granite in the Red Cliff Pond area. The presence of the dykes and lower colour index distinguishes the Ackley Granite Suite from the Koskaecodde pluton. Near Big Blue Hill Pond, fine grained porphyry dykes are common at the contact and, to the northeast of the pond, the granite is distinctly red rather than the usual pink.

Unit 26 contains abundant, 1- to 3-cm-long, K-feldspar phenocrysts in a coarse grained matrix with 1 to 2 percent, 2- to 3-mm-long biotite flakes. Unit 27 is similar to Unit 26 but is only sparsely porphyritic with 1- to 2-cm-long K-feldspar phenocrysts.

More detailed descriptions of the Ackley Granite Suite and the Koskaecodde pluton (Unit 9 of the Ackley Granite of Dickson, 1983) are given in Dickson (1983).

STRUCTURE AND METAMORPHISM

The Long Harbour Group sedimentary and volcanic rocks of the Avalon Zone are generally steeply dipping and possess a single, northeast-trending cleavage. Only a few open folds were found and these are restricted to the sedimentary rocks. Regional metamorphism is weak to absent with the possible development of fine grained micas in the cleaved rocks. The Simmons Brook Batholith is deformed only in the vicinity of faults. The deformation of the Long Harbour Group is generally considered to be part of the Acadian Orogeny (Silurian-Devonian) as Devonian rocks to the south are much less deformed (Williams, 1971). However, the lack of deformation in the Simmons Brook Batholith may indicate that deformation predates this intrusion. This would then require a late Precambrian age for the deformation which is perhaps related to the Avalonian Orogeny.

Units older than the Koskaecodde pluton, in the Gander(?) and Dunnage zones, were deformed prior to emplacement of the pluton; i.e., approximately pre-410–427 Ma. The initial emplacement of ultramafic thrust slices can be considered to be a pre-Middle Ordovician event as ophiolitic rocks in the Gander area are unconformably overlain by Middle Ordovician fossiliferous rocks. However, the ultramafic rocks, in the Hungry Grove Pond map area, were probably not emplaced in their present position at this time but during the deformation of the Baie d'Espoir Group in the Acadian Orogeny. Evidence for this is provided from the D'Espoir Lake area to the west, where probable thrusts with ultramafic inclusions affect rocks of Silurian or Devonian age (e.g., the North Bay Granite; Colman-Sadd, 1976; Dickson and Tomlin, 1983). Parts of this granite have been dated at 396 Ma (U/Pb zircon; Krogh, written communication, 1985). The presence of thrusts is indicated over large areas of the Baie d'Espoir Group, from near the southern limits of the group (Day Cove Thrust of Colman-Sadd, 1974; Figure 4) to central Newfoundland (Colman-Sadd and Swinden, 1984) where ultramafics are considered by them to have been most probably emplaced during the late Silurian or Devonian. The attitude of the Le Pouvoir Fault is uncertain. Foliations are absent in the magnesite and, although the enclosing rocks commonly dip steeply toward the northwest, southeast-dipping structures are also found. Kilfoil *(this volume)* has shown that foliated, ultramafic slivers (Dickson, 1987a) in the Mount Sylvester map area dip moderately to the southeast, parallel to the foliation in the slivers, indicating that the thrust (reverse) faults also dip to the southeast. The dominance of northwest-dipping fabrics along the Le Pouvoir Fault is taken to indicate that the fault dips to the northwest.

The Little Passage Gneiss has been metamorphosed to at least the greenschist facies with the extensive development of biotite and muscovite. Migmatization north of Western Pond indicates that the grade of metamorphism is locally in the amphibolite facies. Contact metamorphism along the contact with the Koskaecodde pluton has converted the psammites into hornfels and cordierite occurs rarely in pelitic bands. The gneisses are strongly foliated and in places the psammitic rocks show a well-developed banding. The banding and the strong schistosity in the pelitic rocks are locally deformed into tight, commonly northeast-plunging folds with steep axial planes.

Metamorphism and apparent complexity of deformation of the Isle Galet Formation increases toward the southeast. The Le Pouvoir Fault marks the boundary between the weakly metamorphosed Units 12 to 14 and more strongly metamorphosed Units 7 to 11. The volcanic units (Units 9 to 11) of the Isle Galet Formation, east of the Le Pouvoir Fault, display a well-developed, steeply dipping, northeast-trending schistosity (S_1) defined by chlorite ± sericite ± epidote and sericite ± chlorite assemblages in the mafic and felsic rocks, respectively. Small, tight folds and intrafolial folds occur locally. The intrafolial folds are formed by the partial transposition of the main (S_1) fabric into gently northeast- or southwest-plunging folds with a steep, axial planar fabric parallel to the main fabric.

West of the Le Pouvoir Fault, the Isle Galet and Riches Island formations are steeply dipping with a slaty cleavage (S_1) parallel to bedding. Gentle, northeast-plunging F_2 folds with gently, east-dipping axial planes and a weak axial planar cleavage occur within the Isle Galet Formation sedimentary rocks (Unit 11). This style of deformation is identical to that found to the north in the Riches Island and St. Joseph's Cove formations (Colman-Sadd, 1976; Dickson, 1987a).

MINERALIZATION AND ALTERATION

The Baie d'Espoir Group has been explored by numerous companies since 1952. Only Westfield Minerals Limited has found significant mineralization with potential for development. The Le Pouvoir horizon hosts four significant stibnite–gold showings and contains several areas with quartz–carbonate alteration near the Le Pouvoir Fault. The Le Pouvoir stibnite showing is a vein of massive, undeformed quartz and coarse-grained stibnite (Plate 8), and contains up to 50 percent stibnite. The vein is hosted by strongly cleaved, chlorite- and chlorite–sericite schist. The vein is about 1 m by 30 cm and is concordant to the schistosity. Rare, large (30 cm) and several, small (5 cm), loose blocks are scattered to the south of the showing for 10 to 15 m. McKillen (written communication to J. Tuach, 1986) indicated that the stibnite also contained anomalous gold values. McKillen (op. cit.) also indicated that three pyrite–stibnite–gold showings occur to the northeast of the Le Pouvoir showing. These showings occur in trenches that exposed quartz-veined, chloritic and pelitic schists with trace amounts of stibnite. As noted previously, Fenton (1981b) obtained anomalous values from quartz–carbonate-veined chloritic schist from the Le Pouvoir Fault zone. Quartz veins along the Collins Brook Fault are locally rusty and contain small amounts of pyrite. Several samples were analyzed for gold but a high value of only 30 ppb was obtained from a vein in tuff (Unit 13).

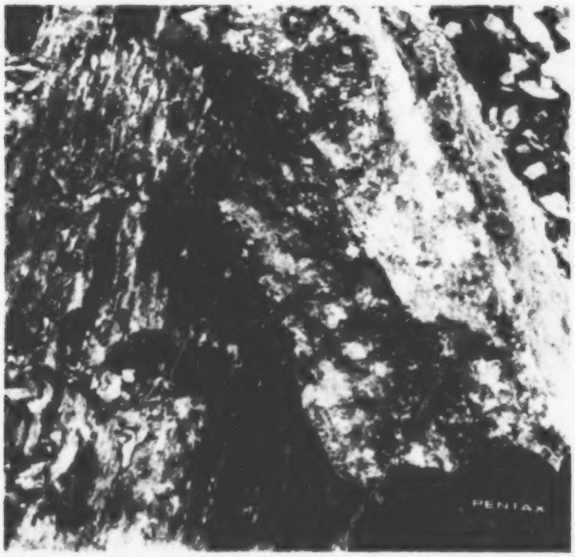


Plate 8. *Block of stibnite (grey)–quartz (white) vein, lying on host chlorite schist, at the Le Pouvoir stibnite–gold showing; lens cap is 5 cm in diameter.*

The Kim Lake horizon contains significant Au and Au–Sb mineralization along strike to the northeast and southwest of the map area. These occurrences are shown in Figure 4. No areas of alteration were found in the Kim Lake horizon in the Hungry Grove Pond map area and quartz veining is rare. However, large areas of the horizon are covered by blanket bog and soil or till sampling is required to assess these areas.

The Little Passage Gneiss, west of the Bay du Nord River, contains numerous alteration zones in which the pelitic and semipelitic schists are locally pyritic. The zones range in size from 100 m^2 to 1 ha and contain abundant randomly oriented, secondary? white mica.

Figure 4 presents a simplified metallogenic map of the Isle Galet Formation and Little Passage Gneiss. The main showings are emphasized and all other known showings are indicated. Many of the minor pyrite showings were reported by Dunlop (1953) and have not been examined since. The most significant mineral occurrences are from the Kim Lake horizon where silicified, arsenopyrite-bearing, foliated tuffs contain gold. It is important to note that the other main showings are spatially related to significant faults and volcanic horizons. The Barasway de Cerf prospect is, however, a stratabound, volcanogenic-exhalative deposit (Swinden, 1982). Gold–stibnite mineralization has been reported in the Little River estuary (Meikle, 1955), 6 km to the northeast of Barasway de Cerf (Figure 4). Much exploration remains to be carried out on the Isle Galet Formation and the potential for further discoveries is high.

The well-cleaved siltstones (subunit 2b) of the late Precambrian Rencontre Formation are commonly rusty with locally extensive gossans. This alteration is due to weathering of the fine grained, disseminated pyrite. Samples were assayed for gold but only background values (<15 ppb) were obtained.

Along the Hermitage Bay Fault, northeast of North East Brook, the fault breccia is extensively chloritized and sericitized. Trace amounts of pyrite were also found. Quartz veins and, rarely, jasper veins occur in the breccia. The Simmons Brook Batholith is also altered along the fault.

Mineralization within the granitoid rocks is generally of limited extent. Beryl has been reported from pegmatite in the North West Brook Complex (Dickson, 1983). Tuach (1984a, b) reported significant Sn and W values from thin gneisen veins in the Ackley Granite Suite, 3 km southeast of Big Blue Hill Pond.

ACKNOWLEDGMENTS

This survey was carried out with the capable assistance of Barry Wheaton. Universal Helicopters provided efficient helicopter service. The manuscript was reviewed by John Hayes, Pat O'Neill and S.P. Colman-Sadd. Their comments are appreciated.

REFERENCES

Aerodat Limited

1979: Report on airborne electromagnetic and magnetic surveys, Kaegudeck Lake, Newfoundland. Hudson's Bay Oil and Gas Company Limited. Unpublished report, 10 pages. [Nfld (1146)]

Anderson, F.D.

1965: Belleoram, Newfoundland. Geological Survey of Canada, Map 8-1965.

1967: Structural studies in the Baie d'Espoir Group, Newfoundland. *In* Collected papers on geology of the Atlantic region—Hugh Lilly Memorial Volume. *Edited by* E.R.W. Neale and H. Williams. Geological Association of Canada, Special Paper 4, pages 193-200.

Baird, D.M., Scott, H.S., Moore, J.C.B. and Walker, W.
1951: Reconnaissance geology of east-central Newfoundland between Sir Charles Hamilton Sound and Bay d'Espoir. Photographic Survey Corporation. Unpublished report, 155 pages. [Nfld. (73)]

Berrangé, J.P. and McCabe, H.B.
1955: Field report on the Kim Lake—Medonnegonix Lake area. Newfoundland and Labrador Corporation. Unpublished report, 34 pages. [2D/3 (33)]

Blackwood, R.F.
1975: The Hermitage Fault and adjacent rocks: northeast corner of the Gaultois map-sheet. Newfoundland Department of Mines and Energy, Mineral Development Division. Unpublished report, 9 pages. [1M (147)]

1978: Northeastern Gander Zone, Newfoundland. *In* Report of Activities for 1977. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 72-79.

1985: Geology of the Facheux Bay map area (11P/9), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-4, 56 pages.

Blackwood, R.F. and Green, L.
1983: Notes on the geology of the Great Gull Lake map area (2D/6) Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 82-71.

Blackwood, R.F. and O'Driscoll, C.F.
1976: The Gander-Avalon boundary in northeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 13, pages 1155-1159.

Butler, A.J. and Davenport, P.H.
1979: Lake sediment geochemical survey of the Fortune—Trinity Bay area, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File Nfld. (1002).

Colman-Sadd, S.P.
1974: The geologic development of the Bay d'Espoir area, southeastern Newfoundland. Ph.D. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 271 pages.

1976: Geology of the St. Alban's map area, Newfoundland (1M/13). Newfoundland Department of Mines and Energy, Mineral Development Division, Report 76-4, 19 pages.

1980a: Geology of south-central Newfoundland and evaluation of the eastern margin of Iapetus. American Journal of Science, Volume 280, pages 991-1017.

1980b: Geology of the Twillick Brook map area, Newfoundland (2D/4). Newfoundland Department of Mines and Energy, Mineral Development Division, Report 79-2, 23 pages.

Colman-Sadd, S.P. and Swinden, H.S.
1982: Geology and mineral potential of south-central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-8, 102 pages.

1984: A tectonic window in central Newfoundland? Geological evidence that the Appalachian Dunnage Zone may be allochthonous. Canadian Journal of Earth Sciences, Volume 21, pages 1349-1367.

Dean, P.L.
1978: Geological reconnaissance New Bay Pond, Gander Lake South, and Kaegudeck Lake areas, Nalco Lot 2; Kaegudeck Lake area. Hudson's Bay Oil and Gas Company Limited. Unpublished report, 7 pages. [Nfld (1061)]

Dickson, W.L.
1982: The southern contact of the Ackley Granite, southeast Newfoundland; location and mineralization. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-1, pages 99-108.

1983: Geology, geochemistry and mineral potential of the Ackley Granite and parts of the North West Brook and Eastern Meelpaeg Complexes, southeast Newfoundland (Parts of map areas 1M/10,11, 14,15,16; 2D/1,2,3 and 7). Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-6, 129 pages.

1986: Mount Sylvester (2D/3), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File map 86-66.

1987a: Geology of the Mount Sylvester (2D/3) map area, Central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division Report 87-1, pages 283-296.

1987b: Hungry Grove Pond (1M/14) map area. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File map 87-56.

Dickson, W.L., Elias, P. and Talkington, R.W.
1980: Geology and geochemistry of the Ackley Granite, southeast Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-1, pages 110-119.

Dickson, W.L. and Tomlin, S.L.
1983: Geology of the D'Espoir Brook map area (11P/16) and part of the Facheux Bay map area (11P/9), south-central Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 83-1A, pages 284-290. *Also in* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 51-56.

Dunlop, W.B.
1954: Exploration in the Bay d'Espoir area. NALCO unpublished report, 13 pages. [1M (41)].

Fenton, J.O.
1981a: Report on the geophysical/geological/geochemical and trenching investigations carried out in the Muddy Hole area of Nalco Lot II. Hudson's Bay Oil and Gas Company Limited. Unpublished report, 16 pages. [Nfld (1237)]

1981b: Report on the geophysical/geological/geochemical and trenching investigations carried out in the Kaegudeck Lake area of Nalco Lot II. Hudson's Bay Oil and Gas Company Limited. Unpublished report, 28 pages. [Nfld (1238)]

Geological Survey of Canada
1969: Aeromagnetic map, Hungry Grove Pond, Newfoundland. Geophysics Paper 4497.

Kilfoil, G.
This volume: Geophysical investigations of lineaments in central Newfoundland.

McHale, K.B.
1985a: The Little River Project. South Central Newfoundland. 1985 Exploration Activities. Westfield Minerals Limited. Unpublished report, 87 pages. [Nfld (1493)]

1985b: Report of exploration activities, Kim Lake area, project 403 (for Westfield Minerals). Tillicum Resources Limited. Unpublished report, 94 pages. [2D/3 (44)]

McHale, K.B. and McKillen, T.N.
1986: The Little River Project. South Central Newfoundland. 1986 Exploration Activities. Westfield Minerals Limited. Unpublished report, 18 pages. [Nfld (1502)]

McKenzie, C.B.
1980: Report on geology and geochemistry; claim block 1414–1418–license 1327–1331. Rio Tinto Canadian Exploration Limited. Unpublished report, 5 pages. [1M (183)]

Meikle, B.K.
1955: The geology of the Little River area, Bay d'Espoir. Unpublished M.Sc. thesis. McGill University, 43 pages. [1M (45)]

Moore, T.H.
1953: Geology of the Garrison Hills Granite contact east of Bay d'Espoir. Newfoundland Department of Mines and Resources, Mines Branch. Report No. 3, 24 pages.

O'Brien, S.J. and Dickson, W.L.
1986: Burgeo, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 86-32.

O'Brien, S.J., Nunn, G.A.G., Dickson, W.L. and Tuach, J.
1984: Geology of the Terrenceville (1M/10) and Gisborne Lake (1M/15) map areas, southeast Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-4, 54 pages.

O'Driscoll, C.F.
1977: Geology, petrology and geochemistry of the Hermitage Peninsula, southern Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, 144 pages.

O'Driscoll, C.F. and Strong, D.F.
1979: Geology and geochemistry of Late Precambrian volcanic and intrusive rocks of Southwestern Avalon Zone in Newfoundland. Precambrian Research, Volume 8, pages 19-48.

Photographic Survey Corporation Ltd.
?1951: Preliminary geological map of the Gander Bay–Baie d'Espoir area. Photographic Survey Corporation Limited. [Nfld (445)]

Saunders, P.D.
1980: Assessment report on geological and geochemical surveys performed in the Hungry Grove Pond area, Newfoundland. Falconbridge Nickel Mines Limited. Unpublished report, 100 pages. [1M/14 (185)]

1981: An assessment report on a lake sediment geochemical survey carried out over part of the Ackley Batholith, southeast Newfoundland. Falconbridge Nickel Mines Limited. Unpublished report, 17 pages. [1M/14 (191)]

Saunders, P.D. and Prince, D.
1977: Geological investigation Nalco Lot 2 Baie d'Espoir. Falconbridge Nickel Mines Limited. Unpublished report, 11 pages. [1M (180)]

Smith, B.L. and White, D.E.
1954: Geology of the Rencontre East area. Geological Survey of Canada. Unpublished report, 46 pages.

Stouge, S.
1980: Lower and Middle Ordovician conodonts from central Newfoundland and their correlatives in western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-1, pages 134-142.

Swinden, H.S.
1980: Economic geology of the eastern Hermitage Flexure. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-1, pages 100-109.

1982: Metallogenesis in the Bay d'Espoir area, southern Newfoundland. Canadian Mining and Metallurgical Bulletin, Volume 75, pages 172-183.

Tuach, J.
1984a: Tin analysis from whole rock samples of the Ackley Granite and Cross Hills Plutonic Complex, southeastern Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File 1M (211), 11 pages.

1984b: Tungsten analyses from quartz−topaz greisen veins, and the economic significance of lithogeochemical trends in the Ackley Granite, southeastern Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File 1M (214), 5 pages.

1987: The Ackley high-silica magmatic/metallogenic system and associated post-tectonic granites, southeast Newfoundland. Unpublished Ph.D. thesis. Memorial University of Newfoundland, 455 pages.

Tuach, J., Kerrich, R., Strong, D.F. and Willmore, L.M.
1985: Variations in oxygen isotopic ratios related to source terranes and to hydrothermal regimes in the Ackley Granite, Newfoundland. *In* Granite-related mineral deposits−geology, petrogenesis and tectonic setting. *Edited by* R.P. Taylor and D.F. Strong. CIM conference, Halifax, Canada. Extended abstracts of papers, pages 285-289.

Tuach, J., Davenport, P.H., Dickson, W.L. and Strong, D.F.
1986: Geochemical trends in the Ackley Granite, southeast Newfoundland: their relevance to magmatic−metallogenic processes in high-silica granitoid systems. Canadian Journal of Earth Sciences, Volume 23, pages 747-765.

Twenhofel, W.H. and MacClintock, P.
1940: Surface of Newfoundland. Geological Society of America, Bulletin, Volume 51, pages 1665-1726.

Vanderveer, D.G.
1982: Preliminary glacial mapping of the Ackley Granite−south half. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-1, pages 233-234.

Wanless, R.K., Stevens, R.D., Lachance, G.R. and Delabio, R.N.
1972: Age determinations and geological studies: K-Ar isotopic ages, Report 10. Geological Survey of Canada, Paper 71-2, pages 89-93.

Westfield Minerals Limited
1986: Press release. *In* Northern Miner, October 27, 1986.

White, D.E.
1939: Geology and molybdenite deposits of the Rencontre East area, Fortune Bay, Newfoundland. Ph.D. thesis, Princeton University, 118 pages. [1M/11 (6)]

Widmer, K.
1950: The geology of the Hermitage Bay area, Newfoundland. Ph.D. thesis, Princeton University, 459 pages. [1M (8)]

Williams, H.
1971: Geology of Belleoram map area (1M/11), Newfoundland. Geological Survey of Canada, Paper 70-65, 39 pages.

Williams, H., Colman-Sadd, S.P. and Swinden, H.S.
1988: Tectono-stratigraphic subdivisions of central Newfoundland. *In* Current Research. Geological Survey of Canada, Paper 88-1A.

Williams, H. and Hatcher, R.D. Jr.
1983: Appalachian suspect terranes. *In* Contributions to the tectonics and geophysics of mountain chains. *Edited by* R.D. Hatcher Jr., H. Williams and I. Zietz. Geological Society of America Memoir 158, pages 33-53.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 165-176

GEOLOGY OF THE EAST HALF OF THE WEIR'S POND (2E/1) MAP AREA AND ITS REGIONAL SIGNIFICANCE

Pat O'Neill and Ian Knight
Newfoundland Mapping Section

ABSTRACT

The eastern half of the Weir's Pond map area is underlain principally by quartzose sandstone and pelite of the Gander Group. Two formations are defined in the Gander Group, the Indian Bay formation, characterized by black pelite, fossiliferous shale, mafic and felsic volcanic rocks, and the Jonathan's Pond formation, comprising quartzite, psammite and grey−green pelite. The definition and position of the Indian Bay formation, hitherto a suspected structural klippe of Dunnage Zone affinity, is revised and interpreted to be gradational with rocks of the Gander Group. Because of the previously discovered fauna in rocks of the Indian Bay formation, the Gander Group, at least in this area, is assigned a late Arenig age.

An ultramafic sliver in the Jonathan's Pond formation coincides with the eastern edge of an aeromagnetic anomaly, which may represent a structurally emplaced ultramafic−mafic body at depth. Synkinematic and posttectonic granites intrude the Gander Group in the northeast.

An early phase of isoclinal F_1 folds have an associated axial planar cleavage, which is the principal tectonic fabric recognized. A second phase of deformation produced open F_2 folds and distinct but heterogenously developed crenulation folds. Metamorphic isograds, based on field mapping, are roughly symmetrical about the plutons.

Either felsic volcanic rocks or partly silicified sandstone of the Indian Bay formation locally contain significant gold concentrations.

INTRODUCTION

The Weir's Pond (2E/1) map area is centred 30 km northeast of the town of Gander in northeastern Newfoundland (see inset, Figure 1). Access to the central portion of the eastern half of the area is provided by old logging roads that connect with Route 360, near Indian Bay. Helicopter-supported fly camps were used to map the northern part of the area. Numerous ponds throughout the east half of the map area make a boat indispensible. Mapping of the Weir's Pond area has been completed at a scale of 1:50,000. Figure 1 shows the general geology of the area.

Little detailed work had been carried out in that part of the Weir's Pond area covered in this report. The rocks in the eastern part of the map area were briefly examined by Blackwood (1978) and Hanmer (1981). Detailed mapping and definition of the Indian Bay formation, in and near Indian Bay Big Pond, was done by Wonderley (Wonderley and Neuman, 1984). Mapping in the Wesleyville (2F/4) area, immediately east of the present study area, was carried out by Williams (1968) and Jayasinghe (1978). No mineral exploration work has been undertaken in the area.

REGIONAL RELATIONSHIPS

Three principal tectonostratigraphic divisions are recognized in the Weir's Pond area: the Gander Group (Units 1 to 7, Figure 1), the Gander River Ultrabasic Belt, and the Davidsville Group. South of Ocean Pond, a small, tectonic sliver of pyroxenite and pyroxene gabbro (Unit 8) occurs in the centre of the Jonathan's Pond formation. The Ocean Pond pluton (Unit 9) and Deadmans Bay Granite (Unit 10), synkinematic and posttectonic granites respectively, intrude the Gander Group.

Jenness (1958) defined the Middle Ordovician Gander Lake Group as a sequence of slate, sandstone, limestone, phyllite and conglomerate exposed near Gander. The Gander Lake Group was later subdivided into conformable lower, middle and upper units (Jenness, 1963). Kennedy and McGonigal (1972) redefined the Gander Lake Group to include only the lower unit and proposed the new term Davidsville Group for the middle and upper parts. They considered that deformation and metamorphism of their Gander Lake Group occurred prior to deposition of the Davidsville Group, and cited, as evidence, the presence of

---

This project is a contribution to the Canada−Newfoundland Mineral Development Agreement, 1984−1989

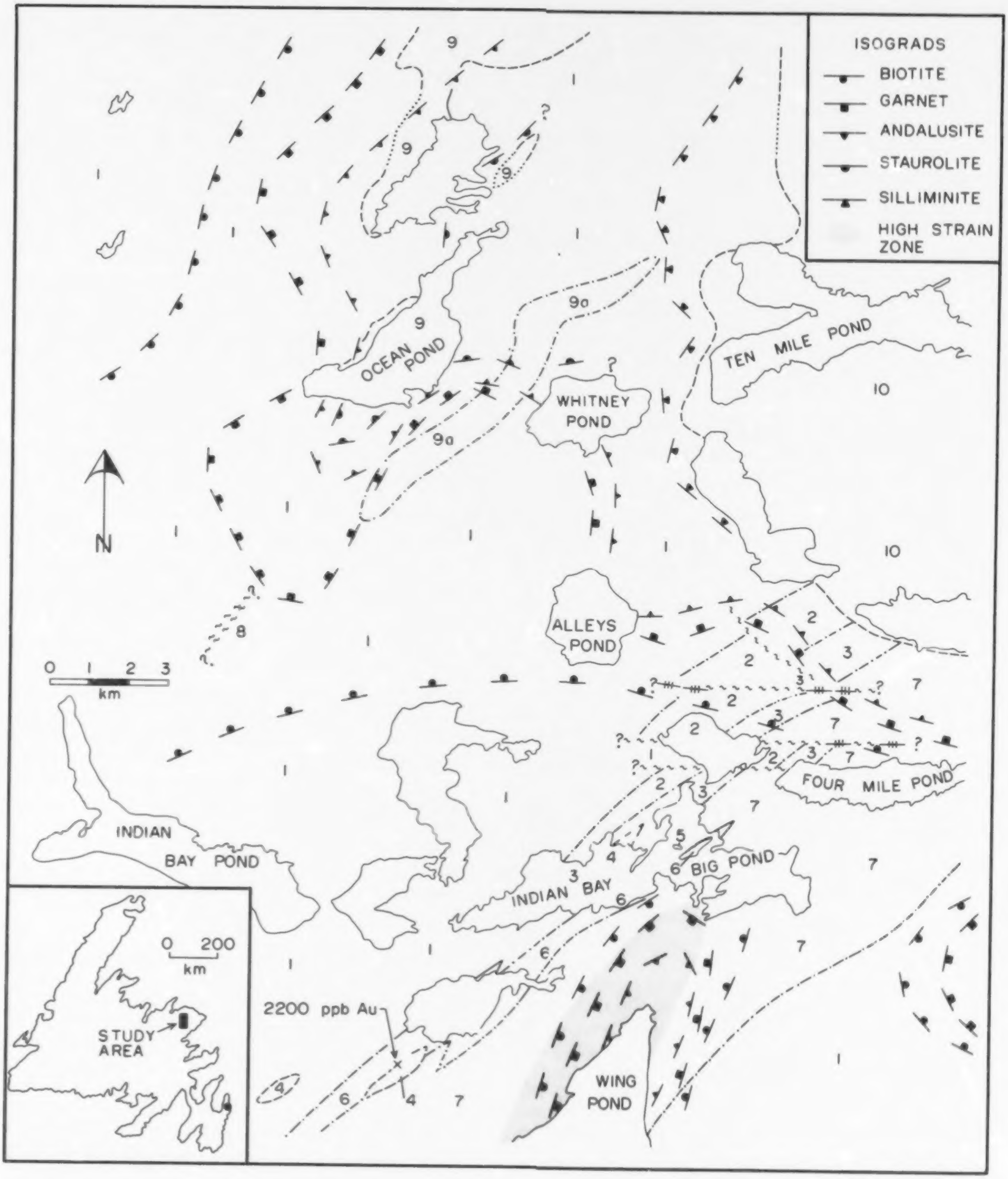

ISOGRADS
BIOTITE
GARNET
ANDALUSITE
STAUROLITE
SILLIMINITE
HIGH STRAIN ZONE
OCEAN POND
WHITNEY POND
TEN MILE POND
ALLEYS POND
FOUR MILE POND
INDIAN BAY POND
INDIAN BAY
BIG POND
WING POND
N
0 1 2 3
km
0 200
km
STUDY AREA
2200 ppb Au
1
2
3
4
5
6
7
8
9
9a
10
?

Figure 1. *Geology of the east half of the Weirs Pond (2E/1) map area.*

LEGEND (FIGURE 1)

SILURO–DEVONIAN OR EARLIER

10 Deadman's Bay Granite: *non-foliated, K-feldspar-megacrystic, biotite granite*

9 Ocean Pond granite: *equigranular muscovite granite, generally moderately foliated;* 9a, *zone containing numerous sheets of Ocean Pond granite and pegmatite*

8 *Coarse grained pyroxenite and pyroxene gabbro, locally undeformed*

LOWER ORDOVICIAN

Gander Group

Indian Bay formation (Units 2 to 7)

7 *Grey and dark-grey psammite, grey–green and black pelite, thin calc-silicate beds*

6 *Medium grained, medium to thick bedded, buff and maroon micaceous sandstone; green and maroon siltstone, minor black pelite, fossiliferous argillaceous rock, minor felsic tuff (?); intraformational pebble and cobble conglomerate; minor grey sandstone*

5 *Pillowed mafic volcanic rock, pillow breccia and/or hyaloclastite*

4 *Felsic to intermediate intrusive rock containing hornblende, feldspar and, rarely, quartz phenocrysts*

3 *Laminated black pelite containing laminae of thin sandy layers, minor, thin, grey sandstone beds, rare black-quartz-granule sandstone and a 6-m chert band*

2 *Grey psammite, grey–green pelite, black pelite and dark-grey psammite*

Jonathan's Pond formation

1 *Medium to thinly bedded grey psammite, grey–green pelite and quartzite, minor quartz-granule sandstone, amphibolite and calc-silicate layers*

---

detrital biotite and garnet, and mafic schist and psammite fragments in basal conglomerate and greywacke of the Davidsville Group. The term Gander Lake Group was informally amended to Gander Group by McGonigal (1973), and formally proposed by Blackwood (1982).

The Gander Group consists predominantly of psammitic and pelitic rocks, which continue northeastward along strike to the Carmanville (2E/8) map area (Currie and Pajari, 1977) and southwestward to the Kaegudeck Lake area (Dickson, 1987). Williams (1968), mapping in the Wesleyville (2F/4) map area immediately to the east of the present study area, defined greywacke and quartzite (Gander Group) in the west as being conformable with muscovite–biotite schists in the east that locally contain garnet, andalusite and sillimanite. These sedimentary rocks and schists exposed in the southwest corner of the Wesleyville area were later included in the Square Pond Gneiss, the term proposed by Blackwood (1976, 1977 and 1978) to define rocks that essentially comprise the biotite zone and higher grade parts of the Gander Group, and included rocks immediately south and west of the Deadman's Bay Granite. The rocks in the eastern part of the Weir's Pond area were only briefly examined by Blackwood (1978). Farther east (outside the map area), migmatite of the Hare Bay Gneiss was interpreted to represent the culmination of eastward-increasing metamorphism within the Gander Group (Blackwood, 1978). The Gander Group, Square Pond Gneiss and Hare Bay Gneiss, together with a suite of (Siluro-Devonian?) synkinematic and posttectonic plutons, define the northeastern Gander Zone (Williams, 1976).

The Deadmans Bay Granite was mapped in the Wesleyville area by Jayasinghe (1976, 1978), who described it as a homogenous coarse grained biotite granite characterized by K-feldspar megacrysts. No satisfactory age is available for this granite (Jayasinghe, 1976).

The Gander Zone is bounded to the west by a complex package of ultramafic to felsic rocks, the Gander River Ultrabasic Belt (Jenness, 1958), which are structurally juxtaposed with lower units of the Ordovician Davidsville Group. North of Weir's Pond, in the Carmanville (2E/8) map area, Currie and Pajari (1977) state that the Gander and Davidsville groups are in conformable contact where the Gander River Ultrabasic Belt is absent. Blackwood (1982) advocates the same relationships south of Gander Lake. The Davidsville Group and Gander River Ultrabasic Belt lie within the Dunnage Zone (Williams, 1976).

Hanmer (1980) briefly examined rocks in the southeast part of the map area as part of a regional structural study, and proposed that much of the northeastern Gander Zone is an Acadian ductile shear zone exhibiting a dominant component of sinistral motion.

The most recent contribution to the geology of the study area was the definition of the Indian Bay formation, exposed near Indian Bay Big Pond by Wonderley and Neuman (1984). Fossils from a pelitic unit give a late Arenig age. The first author favoured interpreting the Indian Bay formation as allochthonous, representing a thrusted slice of Dunnage Zone rocks; alternative models were essentially based on the Indian Bay formation being autochthonous.

Regional foliations in the Davidsville Group and Gander River Ultrabasic Belt trend northeast, whereas the regional foliation in the Gander Group is north to north-northeast trending. Metamorphic grade varies regionally from greenschist facies in the west to amphibolite facies in the northeast and central parts; in the south and southeast, the rocks are mostly greenschist, with the exception of a small area around Wing Pond.

GENERAL GEOLOGY

Gander Group (Units 1 to 7)

In this report, the Gander Group is informally divided into the Indian Bay and Jonathan's Pond formations. The term Indian Bay formation (Wonderley and Neuman, 1984) is used, but redefined to include units gradational between the Jonathan's Pond and Indian Bay formations. The area underlain by the Indian Bay formation is also increased (Figure 1) so that it extends from Big Bear Cove Pond in the north to (at least) Little Wing Pond in the south. The term Jonathan's Pond formation is used for the remainder of the Gander Group to the west and east of the Indian Bay formation.

Jonathon's Pond formation (Unit 1). This formation includes most of the rocks formerly described (McGonigal, 1973; Blackwood, 1982) as typical Gander Group sedimentary rocks. Interbedded psammite and pelite are the major rock types (Plate 1); pelite, quartz-granule sandstone, quartzite, mafic sills and/or dykes and calc-silicate layers or lenses, in order of descending abundance, form the remainder of the group.

Despite a strongly developed foliation, bedding is well preserved in these rocks, and is due mostly to the contrast in composition and grain size between the psammite and pelite. There is a marked lack of gradation between these two rock types, and in some localities, bedding planes are defineable between quartzite and psammite even though they are compositionally similar. Although bed thickness varies due to deformation, it typically ranges from a few millimetres in the more pelitic parts to approximately 2 m in quartz-rich units. Quartzitic psammite is generally medium bedded; locally, however, it contains a thin planar stratification.

Clastic textures are preserved in the lowest grade rocks in the southwest; here the sandstone is a grey, fine- to medium-grained, quartz-dominated rock in which feldspar typically forms less than 10 percent. Quartz-granule sandstone, which contains 60 to 90 percent, commonly blue, quartz, shows a bimodal size distribution of quartz grains; larger grains range from 1 to 3 mm across whereas smaller grains are less than 0.2 mm across. The rocks are immature to moderately mature, containing 10 to 30 percent matrix that is recrystallized to fine grained quartz and white mica. Sorting is moderate and grains are subangular. Mafic bands, generally 0.5 to 2 m thick, form less than 1 percent of total exposures. Locally, they crosscut the sedimentary layering, but typically are conformable. They are interpreted to be pretectonic intrusive rocks.

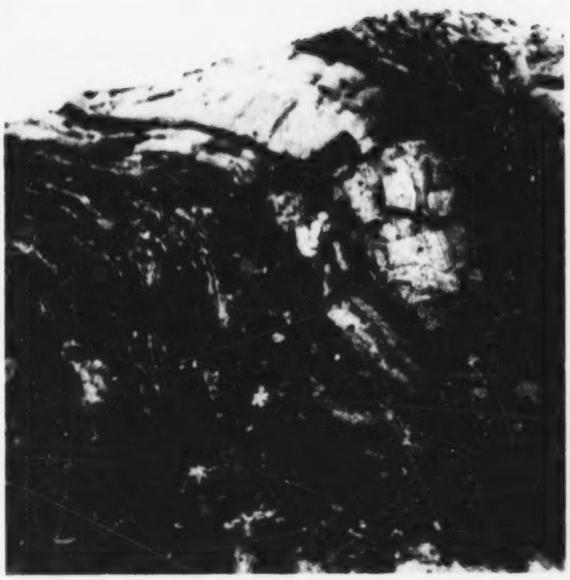


Plate 1. *Thin to medium bedded, quartzitic psammite, psammite and pelite of the Jonathan's Pond formation (Unit 1).*

Psammite commonly contains detrital calc-silicate minerals. These minerals locally form layers, 1 mm to several centimetres thick, and isolated pods, 5 to 20 cm across, that may have been calcareous nodules.

In low-strain zones or areas where the bedding is normal to foliation, there are locally short sections (< 25 m) that give some indication of the character of the original sediment (Figure 2). A 20-m section (Section A, Figure 2), 1 km north of the east end of Indian Bay Pond, contains distinctive, green–white-weathering, current-bedded siltstone. Pelite units, up to 500 cm thick, vary from structureless pelite to thinly (< 3 cm) and thickly (20 to 60 cm) interbedded pelite and psammite. The psammite is typically fine to very fine grained, and exhibits sharp, planar to locally erosive or scoured bases, and sharp planar tops. Above the base, the sedimentary character of sand beds is variable. Some cross-lamination occurs in the psammite and is locally undulose. Thicker sand interbeds are 0.9 to 30 m thick, and subtly graded from medium fine to fine grained. Some psammite

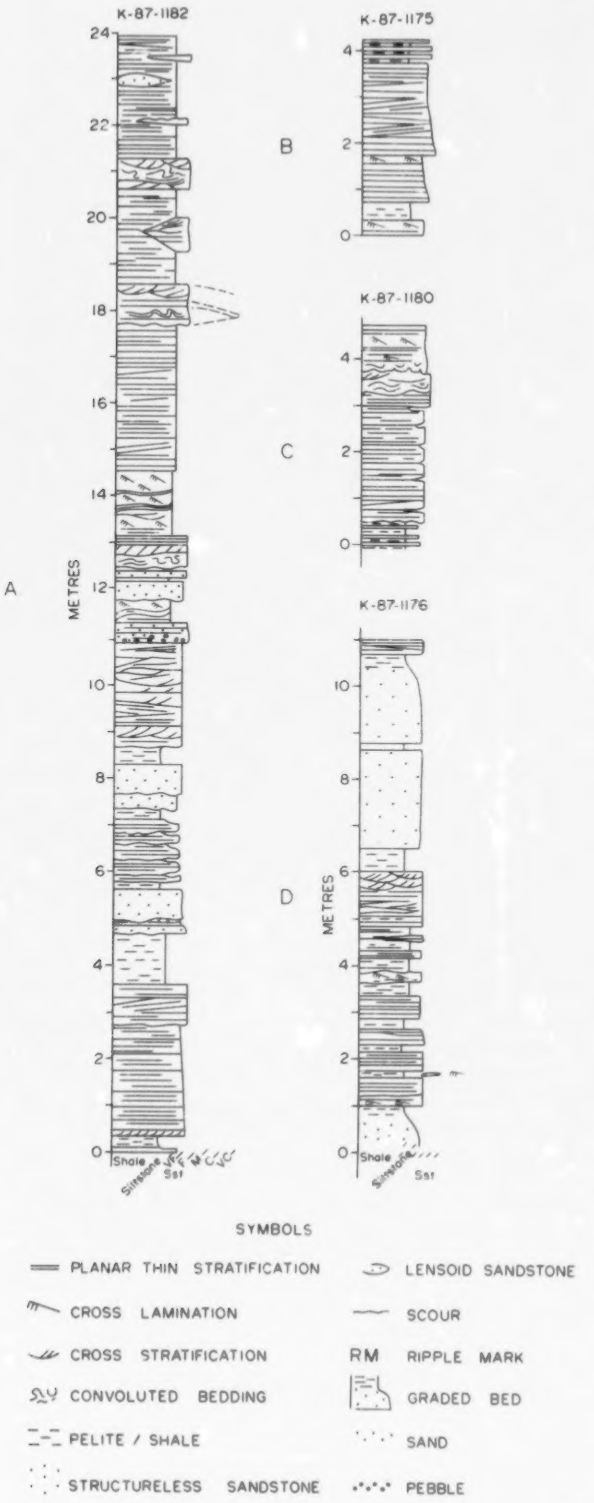


Figure 2. *Representative stratigraphic sections from Jonathan's Pond formation.*

beds are apparently structureless, but locally contain scour surfaces between beds and minor lamination. These massive sandstone beds either grade up into pelite or are overlain by beds of laminated and crossbedded psammite. The most common structure is thin (< 1 cm) planar lamination. Other psammite beds are composed of planar-laminated sandstone separated every 20 to 80 cm by either shallowly inclined surfaces or by pelitic partings. A single 10-cm-thick set of possibly planar cross-stratification overlies the basal contact of one unit. Crossbeds, however, are more commonly developed at the top of the thick bedded psammite. The trough cross-sets rework the top of the laminated sandstone and are commonly convoluted. A prominent erosional surface locally underlies either the cross-sets or a bed of stratified sandstone consisting of clean, medium- to coarse-grained quartz arenite containing well rounded quartz grains. This suggests that in some sections, there are coarsening- and maturing-upward sequences (Section C, Figure 2).

Psammite also forms lenticular bodies, 15 to 80 cm thick and several metres long, enclosed by the siltstone facies. Sharp bases and convex-upward tops characterize the sandstone bodies. The core of the thicker lenses contain undulose to planar laminations. Offlapping, narrowing, sandstone wedges of gently inclined to curved foresets occur near the margins of the sandstone bodies. Trough crossbeds produced by unidirectional paleoflow rework the top of the sandstone bodies. Crossbeds dominate the entire thickness of other sandstone beds. Ripple marks form the top of some of the thinner sandstone lenses, which have internal wavy lamination. The enclosing siltstone is up to 10 m thick and displays wavy lamination to ripple cross-lamination, including climbing-ripple drift.

Indian Bay formation (Units 2 to 7). The Indian Bay formation is a northeast-striking sequence of metasedimentary and metavolanic rocks, exposed south of Big Bear Cove Pond. Units are sequentially numbered from west to east, but stratigraphic indicators are lacking and the relative ages of the units are unknown. Contacts between all adjacent units within this formation were not observed; therefore, the complete stratigraphic continuity of Units 2 to 7 is partly inferred. The contacts between the Jonathan's Pond (Unit 1) and Indian Bay formations are placed at the western margin of Unit 2 and the eastern margin of Unit 7 (see Figure 1); these two units are gradational into Unit 1.

Unit 2 comprises rocks that are gradational between the Jonathan's Pond and Indian Bay formations, and is best observed north of Little Bear Cove Pond, in an area where exposure is semi-continuous. Within this unit, grey sandstone and grey–green pelite, typical of the Jonathan's Pond formation, is interbedded with dark-grey sandstone and black laminated pelite (Plate 2). The rocks are generally medium to thinly bedded. Black pelite, which defines the most distinctive change in sediment type, increases eastward through Unit 2, forming approximately 50 percent of individual exposures near its eastern boundary. The laminae in the black pelite are alternating grey and black layers, interspersed with 1- to 2-cm-thick light-grey sandstone bands. The dark-grey colour of the sandstone is due to 5 to 10 percent

Plate 2. *Interbedded quartzitic psammite and black pelite–siltstone in Unit 2, defining the gradational contact between the Jonathan's Pond and Indian Bay formations.*

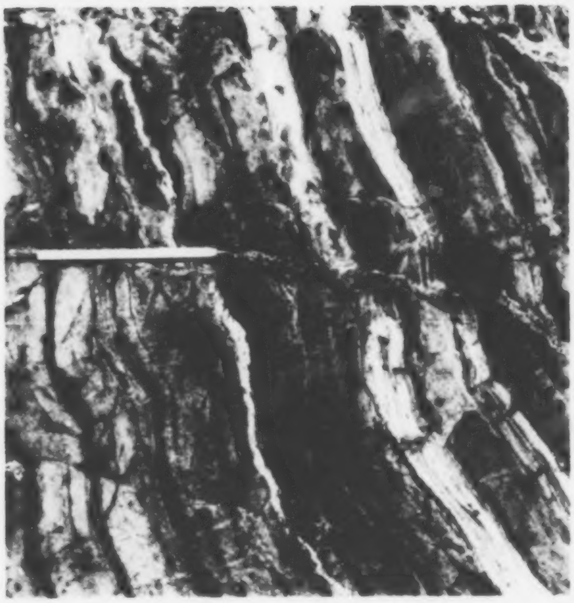


Plate 3. *Thinly bedded and laminated black pelite–siltstone containing minor sandy layers, in Unit 3 of the Indian Bay formation.*

opaque material (pyrite or graphite or both); otherwise the rock is petrographically very similar to quartzitic sandstone of the Jonathan's Pond formation.

Unit 3 consists predominantly of black pelite, ubiquitously laminated with millimetre-thick sandy layers and rare black, quartz-granule sandstone (Plate 3). Locally, thin or medium bedded, dark-grey quartzitic sandstone is interbedded with the pelite. On the western margin of this unit, a distinctive 6-m-thick chert band, bounded by black pelite, occurs along strike for several kilometres.

Unit 4 is a sub-intrusive or extrusive porphyry of intermediate to felsic composition, containing feldspar phenocrysts and chloritized hornblende laths from 1 to 6 mm in length. Quartz phenocrysts are locally present and form < 5 percent of the rock. The matrix is aphanitic and green or purple in the three exposures near Indian Bay Big Pond, whereas in the two exposures south of Southern Pond, the matrix is grey. Brecciation is locally extensive and breccia fragments are cemented by calcite. Disseminated pyrite and profuse quartz-vein development occur locally. (Contacts between this unit and adjacent units were not observed.)

Unit 5 consists of two exposures of pillowed mafic volcanic rock that occur on two small islands in Indian Bay Big Pond, east of Unit 4. The pillows range up to approximately 1 m in diameter. Their morphology is very well preserved, although the rock is extensively altered to a grey-green, calcite-rich assemblage. Unequivocal top indicators were not observed in the pillows. A hyaloclastite, which contains blocks of vesicular mafic material, is exposed nearby and occurs as numerous boulders on the shoreline. Unit 5 is not exposed north or south of the pond, but some boulders of mafic material were noted on the shores of Little Bear Cove Pond to the north. The unit's exact relationship to other units of the Indian Bay formation is uncertain because of its restriction to the islands.

Unit 6 consists of micaeous, medium grained, medium to thick bedded, buff and maroon sandstone, thinly bedded, maroon and green siltstone, and black pelite. The micaceous character and colour of the sandstone differentiate it from sandstone of the Jonathan's Pond formation. Boulders of fossiliferous argillite and fine grained sandstone, which are particularly common on the northern shores of Indian Bay Big Pond, are considered to be from this unit. Some exposures of a fine grained, sandy to argillaceous rock occur on the northern and southern shores of the pond, and are similar to the rock matrix in which the fossils are preserved; however, no fossiliferous material has been found *in situ*. Boulders from an intraformational, pebble and cobble conglomerate, which contain detritus from the Indian Bay formation, are common on the shores of Indian Bay Big Pond and Little Bear Cove Pond. Grey to dark-grey sandstone, similar to that of the Jonathan's Pond formation, is locally intercalated with the buff and maroon sandstone of Unit 6.

Unit 7 is gradational between the Jonathan's Pond and Indian Bay formations. It consists of interbedded grey and dark-grey sandstone, grey-green and black pelite and numerous calc-silicate bands, the latter are particularly common in the northern part of the area. North of Four Mile Pond, small patches of gabbro pegmatite occur in several small exposures that are characterized by sporadic occurrences of very coarse grained andalusite. The andalusite is locally intimately associated with the gabbro, which may represent the surface manifestation of a larger gabbroic body (coincides with a high aeromagnetic anomaly). Unit 7 is not well defined, as many of the rocks are highly strained, and petrographic work is necessary for further evaluation.

Ultramafic Rocks (Unit 8)

A fault-bounded, 100- to 200-m wide sliver of pyroxenite and pyroxene gabbro extends for approximately 2 km along strike north of Indian Bay Pond. The actual contacts with the enclosing rocks of the Jonathan's Pond formation were not observed. The western margin of the body is intensely foliated whereas that part of the body exposed close to the eastern edge is relatively undeformed. Pyroxenite predominates on the western side and passes into pyroxene gabbro and gabbro on the eastern side. The gabbro appears to be unaltered. Gabbro pegmatite and locally granitic pegmatite (the latter containing tourmaline) intrude the gabbro.

Ocean Pond Pluton (Unit 9)

The Ocean Pond pluton comprises several northeast-trending small bodies exposed near Ocean Pond and Little Ocean Pond in the north-central part of the Weir's Pond area. It is an equigranular, muscovite granite that is typically foliated. The intensity of the foliation varies from place to place and is usually defined by an alignment of muscovite. The foliation is subhorizontal or shallowly dipping, either to the northwest or southwest. Small garnets, up to 3 mm across, occur sporadically, and tourmaline is common, forming several modal percent locally. In one exposure, tourmaline defines a subhorizontal northeast-trending lineation.

Pegmatites, characteristically containing coarse grained garnet and tourmaline, and rarely beryl, are associated with this granite. They comprise more than 60 percent of exposures west of Whitney Pond, and this zone (subunit 9a) is separated from the Jonathan's Pond formation.

The Ocean Pond pluton is a synkinematic, probably synmetamorphic, granite that was intruded after the D_1 deformation.

Deadman's Bay Granite (Unit 10)

The Deadman's Bay Granite, outcropping in the northeastern part of the area, is a posttectonic biotite granite that contains distinctive K-feldspar megacrysts ranging up to several centimetres across. This granite cuts across structures of all ages in the Gander Group, and, in the south, cuts across the sillimanite isograd. Its contact with the Gander Group is intrusive and marked by blocks of psammite and pelite in a granite matrix over a zone several metres wide. Granitic material also intrudes the sedimentary rocks along bedding and foliation planes in a restricted zone close to the contact. Isolated K-feldspar megacrysts clearly grow in the sedimentary rocks at the contact zone. The granite has very few pegmatites associated with it.

DEFORMATION

All the units described above, with the exception of Units 8 to 10, exhibit the effects of two stages of deformation. During D_1, a penetrative foliation, striking north-northeast to northeast, developed in all rock types. This fabric is the earliest foliation recognized and is therefore designated S_1. Dips of S_1 are shallow near Indian Bay Pond, moderate in the central and western portions and become steep toward the Deadmans Bay Granite on its southwest margin; it also steepens toward a high-strain zone at Wing Pond. S_1 is axial planar to microscopic and mesoscopic tight to isoclinal folds in multilayered sequences. Refraction of S_1 is locally pronounced due to sharp contacts between beds and a lack of grading in the metasedimentary rocks. Variation in bed thickness and composition has, in places, caused disharmony in folds (Plate 4). F_1 fold hinges commonly are not seen, but tend to vary in the amount and direction of plunge due to later deformation. Plunges are generally westerly, ranging from vertical (reclined) to approximately 10°.

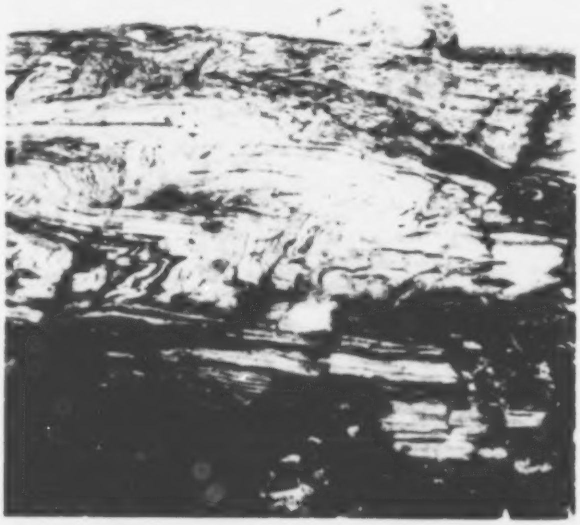


Plate 4. *Disharmonic folds in thinly bedded quartzitic psammite, psammite and semipelite of the Jonathan's Pond formation.*

A second phase of deformation has folded S_1 around upright, open to tight, microscopic to mesoscopic folds (Plate 5). F_2 folds are most commonly developed as crenulations that locally have an associated crenulation cleavage (Plate 6), which strikes north-northeastward and dips steeply either to the northwest or southeast. In the central parts of the area,

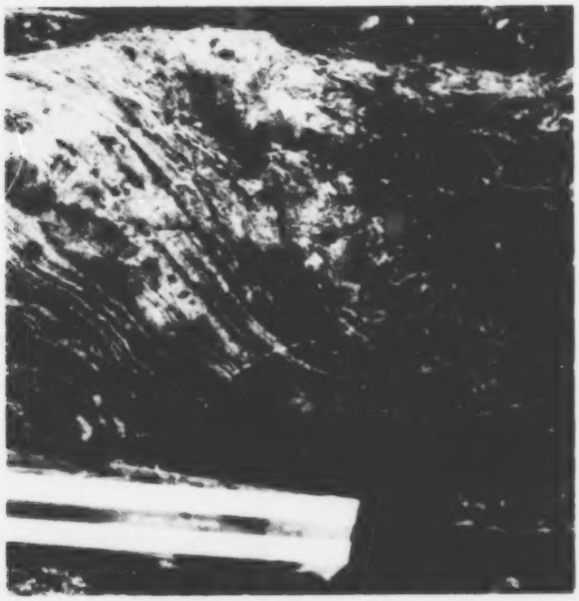


Plate 5. *Isoclinal, recumbent F_1 folds, folded around open F_2s; the pelitic layers contain abundant F_2 crenulations.*

Plate 6. *Asymmetric crenulation cleavage with associated cleavage and lineation in the Jonathan's Pond formation.*

a subhorizontal, crenulation lineation is very well developed and lies parallel to F_2 fold axes. The intensity of the second-deformation phase increases toward the granitic plutons, but within the sillimanite zone, F_2 crenulations are not exceptionally well developed. Brittle-deformation effects are represented by kink bands, which are common throughout the area and locally occur as conjugate sets.

High-Strain Zone

Near Wing Pond, rocks in the Gander Group are highly strained in a zone that is a minimum of 4 to 5 km wide and extends in a northeasterly direction for a minimum of 7 km. It extends southward outside the map area. Quartz veins are profusely developed (Plate 7) in pelitic and semipelitic rocks, and the majority of these veins are folded or show some strain effects. The foliation is intensely developed, marked by millimetre-wide discrete foliae, numerous quartz platelets and ribboned quartz veins. Folds are locally complex (Plate 8) exhibiting curvilinear fold axes that commonly curve through 90°. Asymmetric folds defined by quartz veins are later features; they apparently fold the mylonitic fabric and have consistent vergence. High strain is also evident in rocks north of Little Bear Cove Pond but its development is more heterogenous.

Plate 7. *Profuse quartz veins variably deformed in the high-strain zone near Wing Pond.*

METAMORPHISM

The ubiquitous occurrence of a pelitic facies in most exposures of the Jonathan's Pond and Indian Bay formations, in the Weir's Pond area, allows evaluation of the continuous variation in metamorphic grade from west to east. Limited bulk compositional variation in pelite composition has resulted in the identification of a simple progressive change in metamorphic facies from greenschist through to upper amphibolite. Biotite, garnet, andalusite, staurolite and sillimanite isograds, as defined in the field (Figure 1), are very roughly symmetrically related to the Ocean Pond pluton

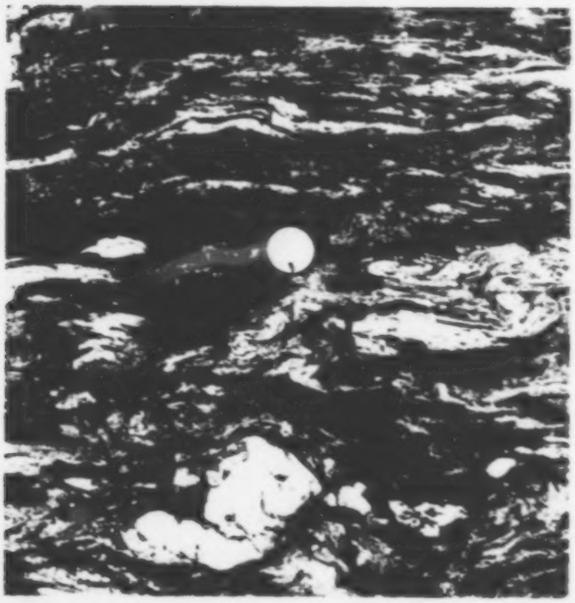


Plate 8. *Complexly folded quartz veins in the high-strain zone.*

Plate 9. *Disrupted sillimanite-rich pods in pelitic 'matrix' in the sillimanite zone.*

and the Deadmans Bay Granite. In the northwest and south, the assemblage muscovite–chlorite–quartz–plagioclase in pelitic and semipelitic rocks, and chlorite–calcite–epidote–plagioclase in mafic rocks, is indicative of low greenschist facies (Winkler, 1979). Farther east, biotite becomes a stable phase coexisting with muscovite and chlorite. At higher grades, the stable asemblage is garnet (almandine?)–biotite–muscovite–chlorite; chlorite locally persists up to the staurolite zone. Andalusite, coexisting with biotite and garnet, is common around Ocean Pond and Little Ocean Pond, and forms large crystals up to several centimetres long, particularly in association with quartz in veins. The beginning of the amphibolite facies is defined by the appearance of staurolite, coexisting with garnet and biotite, which occurs sporadically and typically forms large crystals up to 2 cm across. The andalusite and staurolite isograds appear to cross the outcrop pattern of the Ocean Pond Pluton.

At 1 to 5 km from the western margin of the Deadmans Bay Granite, andalusite is replaced by sillimanite and the two polymorphs coexist over a several-hundred-metre-wide transition zone; sillimanite commonly rims the andalusite. Sillimanite grows profusely in pelitic and semipelitic rocks in the sillimanite zone, forming fibrolite buttons. Evidence of the enhanced mobility of the rock is given by disrupted sillimanite-rich layers in a psammitic matrix (Plate 9). Locally, in the northeast, small, granitic sweats define the beginning of anatexis. At the southern margin of the granite, the pluton cuts across the sillimanite isograd into the andalusite zone. Evaluation of the relationship between the metamorphism and the granites will require a more detailed petrographic analysis.

Near Wing Pond, biotite, garnet and andalusite isograds occur, and outline an isolated metamorphic high or culmination. These isograds are roughly symmetrical about an elongate aeromagnetic high that is probably a continuation of that at Four Mile Pond.

MINERALIZATION

That part of the northeastern Gander Zone examined here has not previously attracted any mineral exploration companies, principally because of the apparently barren and monotonous nature of the Gander Group. However, recognition of the Indian Bay formation (Wonderley and Neuman, 1984) and its intermediate to felsic volcanic rocks makes the area an attractive exploration target. A grab sample taken south of Southern Pond consisted of representative chips of pyrite-rich rock and crosscutting quartz veins. The exposure sampled is near the edge of a small felsic body, and may contain felsic volcanic and/or patchily silicified psammitic rock; the sample assayed 2200 ppb gold. A conglomeratic unit mapped south of this area by Blackwood (1977) implies that the Indian Bay formation continues along strike to the southwest; therefore, the volcanic rocks may be more extensive. The mafic and felsic–intermediate volcanic rocks exposed at Indian Bay Big Pond are considered to be part of a single volcanic episode contemporanaeous with the sedimentary rocks of the Indian Bay formation.

The contact zone between the chert and laminated black siltstone of Unit 6 locally contains disseminated pyrite and molybdenite. A grab sample assayed 123 ppm molybdenite and 1.5 ppm silver. Molybdenite specks were also noted in pegmatites associated with the Ocean Pond pluton.

DISCUSSION

The depositional setting of the psammite and pelite of the Jonathan's Pond formation is still uncertain. Sharp interbedding of well sorted, quartz-rich, very fine- to medium-grained sandstone with pelite is the characteristic feature of the succession. This suggests that each sandstone bed represents a distinct event when sand was transported into a mud-dominated depositional setting. The well sorted, mature, quartzose nature of the sandstone, is possibly indicative of shallow-marine, near-shore or shelf environments (Pettijohn *et al.*, 1973). This may suggest recycling of earlier sands, some of which may have been aeolian.

Massive graded sandstone suggests deposition from a decelerating current, possibly a turbidity current or liquified sand flow. Most of the sandstone, however, whether amalgamated or interbedded with pelite, is characterized by apparently planar thin stratification and lamination (some of this planicity may be due to tectonic flattening). However, the presence of some undulose lamination, slight discontinuity between stratification and internal scours, and convex-upward lenticular sandstone bodies, composed of similar lamination, suggests many of these beds may be composed of hummocky cross-stratification rather than true plane beds. If this is true, the sands were transported into a muddy shelf by storms and by density currents, and deposited below or fairly close to fair-weather wave base (cf. Walker, 1984). Crossbeds, ripple marks or prominent scours, overlain by better sorted sandstone at the top of the same thick sandstone bed or sandstone lens, suggest that the storm-deposited sands were later reworked by bottom currents during lesser storms or during fair weather, further indicating deposition close to this fair-weather wave base.

Thick planar stratified sands can also occur at the beach face or in washover fans in siliciclastic shoreline sequences (Reinson, 1984). The stratified sands, however, in these settings, are associated with distinctive sequences of offshore to subaerial sands and muds with a predominance of cross-stratification, both of which are generally lacking in the Jonathan's Pond formation. Planar stratified sands are also common in ephemeral, sandy fluvial systems of semi-arid settings (Tunbridge, 1981). The sands are deposited by flash-flood-generated streams that rapidly decelerate, producing only upper-flow plane beds. However, further evidence for a subaerial, semi-arid depositional setting for the rocks of the Jonathan's Pond formation is absent.

The Indian Bay formation has a three-fold significance. Firstly, it includes argillite or fine grained sandstone that contains the only fossils (late Arenig–early Llanvirn) found to date in the northeastern Gander Zone (Wonderley and Neuman, 1984). Secondly, this study defined a gradational transition between the Indian Bay and Jonathan's Pond formations, indicating the Gander Group is late Arenig in this area. Thirdly, the formation contains intermediate to felsic volcanic rocks, previously unrecognized, that are locally mineralized.

Sandstone exposures at Gander Lake (McKerrow and Cocks, 1976) and 2 km southwest of Weir's Pond (O'Neill, 1987; Boyce *et al., this volume)* also contain fauna of late Arenig to early Llanvirn age, and are included in the Davidsville Group. Fossils collected from bioclastic limestone on the northwest shore of Weir's Pond indicate a late Llanvirn to early Llandeilo age (Blackwood, 1978; Stouge, 1979). Williams (reported in Dean, 1978) collected middle Caradoc graptolites from black shales above this exposure on Weir's Pond.

If these rocks containing the late Arenig, Llanvirn–Llandeilo and Caradoc fossils are presumed conformable, a 25-Ma time span is defined by the lower part of the Davidsville Group. The basal part of the Davidsville Group may either form a condensed sequence, or, alternatively, disconformities may be present within the sequence that are now obscured by complex structure. The presence of late Arenig rocks in the Gander and Davidsville groups implies that they are partly time equivalent.

The sandstone of late Arenig age from southwest of Weir's Pond is quartz rich and petrographically similar to Gander Group sandstone; however, it does contain some volcanic fragments. This suggests that volcanic islands or island arcs formed a major source area.

The lower Davidsville Group was deposited after rocks of the Gander River Ultrabasic Belt were emplaced and eroded, providing detritus for the 'basal' conglomerate of the Davidsville Group. Final structural juxtapositioning of the Gander and Davidsville groups and the Gander River Ultrabasic Belt occurred in post-Middle Ordovician times. The contact zone of the Gander and Davidsville groups in the Carmanville area (several kilometres north-northeast of Weir's Pond) is interpreted as a mylonite zone, at least 1 km wide (Ken Currie, personal communication, 1987). Petrographic work on samples from the Gander River Ultrabasic Belt in the Weir's Pond area, shows that many rocks are intensely foliated and locally mylonitic.

The occurrence of the ultramafic rock in the centre of the Jonathan's Pond formation is significant in several respects. It is the first such isolated piece of ultramafic rock discovered within the Gander Group in the northeastern Gander Zone. Spatially, it coincides with the eastern edge of an aeromagnetic anomaly that extends, on a northeasterly trend, from Home Pond in the south to west of Little Ocean Pond in the north. In the Carmanville area to the north, the anomaly terminates; however, if its trend is extrapolated northward it would intersect the Gander River Ultrabasic Belt at an acute angle. Its northern terminus may also be related to the presence of a mylonite zone several kilometres northeast of Weir's Pond (Currie, personal communication, 1987). The ultramafic occurrence agrees with an ultramafic–mafic block modelled by Miller *(in preparation)* to explain the aeromagnetic anomaly. It is uncertain whether this ultramafic body is an imbricate slice of Dunnage Zone material, part of a basement block upon which the Gander Zone has been thrust, or part of original basement to the Gander Zone. Alternatively, the anomaly may reflect a major gabbro intrusion such as at Rodeross Lake in south-central Newfoundland (S. Colman-Sadd, personal communication, 1987).

The small patches of gabbro noted in Unit 7 north of Four Mile Pond are also important. Miller *(in preparation)* has modelled an aeromagnetic anomaly in that area as a mafic block representing a thrusted slice of Dunnage Zone material. If the metamorphic isograds that coincide with this anomaly near Wing Pond were produced by a localized thermal anomaly associated with the magnetic high, this would appear to mitigate against this mafic block being a thrusted (i.e., cold) slice, and would suggest an intrusion. The geology of this area is further complicated by the high-strain zone that affects all the rocks involved.

SUMMARY

1:50,000 mapping of the Weir's Pond area has now been completed. Two main divisions are recognized in the Gander Group: the Jonathan's Pond and Indian Bay formations, which are considered to be gradational. The Jonathan's Pond formation principally comprises psammite and pelite, and minor quartzite, mafic layers and calc-silicate lenses or layers. The gradational contact between the two formations is defined north of Little Bear Cove Pond, where black pelite is intercalated with psammite. The definition of a gradational contact between the Indian Bay and Jonathan's Pond formations implies a late Arenig age for the Gander Group in this area. Mafic and felsic to intermediate volcanic rocks are contemporaneous with sedimentary rocks of the Indian Bay formation. A promising gold assay of 2200 ppb occurs in a possible felsic volcanic exposure near Southern Pond.

All the sedimentary rocks in the area exhibit the effects of two stages of deformation. D_1 produced isoclinal folds, to which the axial planar fabric is the principal regional foliation. D_1 folds were later folded around open to tight, microscopic- to mesoscopic-scale D_2 folds that have an associated crenulation cleavage. A prograde series of metamorphic zones, defined by biotite, garnet, andalusite, staurolite and sillimanite isograds, outline a high-temperature–low-pressure type of metamorphism. The isograds are approximately symmetrical about, but locally crosscut, granitic plutons.

ACKNOWLEDGMENTS

Christopher Beer is thanked for his capable and diligent assistance throughout the field season. Sean O'Brien and Steven Colman-Sadd are thanked for critically reading early drafts of the manuscript.

REFERENCES

Blackwood, R.F.
1976: The relationship between the Gander and Avalon Zones in the Bonavista Bay region, Newfoundland. M.Sc. Thesis, Memorial University of Newfoundland, St. John's, 156 pages.

1977: Geology of the Hare Bay area, northwestern Bonavista Bay. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-5, pages 7-14.

1978: Northeastern Gander Zone. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, 8 pages.

1982: Geology of the Gander Lake (2D/15) and Gander River (2E/2) area. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-4, 56 pages.

Boyce, W.D., Ash, J.S., O'Neill, P. and Knight, I.
This volume: Ordovician biostratigraphic studies in the central mobile belt and their implications for Newfoundland tectonics.

Currie, K.L. and Pajari, G.E.
1977: Igneous and metamorphic rocks between Rocky Bay and Ragged Harbour, Northeastern Newfoundland. *In* Report of Activities, Part A. Geological Survey of Canada, Paper 77-1A, pages 341-346.

Dean, P.L.
1978: The volcanic stratigraphy and metallogeny of Notre Dame Bay, Newfoundland. Geology Report # 7, Memorial University of Newfoundland, St John's, 205 pages.

Dickson, W.L.
1987: Geology of the Mount Sylvester (2D/3) map area, central Newfoundland. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 283-296.

Hanmer, S.
1981: Tectonic significance of the northeastern Gander Zone, Newfoundland: an Acadian ductile shear zone. Canadian Journal of Earth Sciences, Volume 18, pages 120-135.

Jayasinghe, N.R.
1976: Geology of the Wesleyville area, Newfoundland, M.Sc. Thesis, Memorial University of Newfoundland, St. John's, 288 pages.

1978: Geology of the Wesleyville (2F/4) and the Musgrave Harbour east (2F/5) map areas, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-8, 11 pages.

Jenness, S.E.
1958: Geology of the Gander River Ultrabasic Belt, Newfoundland. Geological Survey of Newfoundland, Report 11, 58 pages.

1963: Terra Nova and Bonavista Bay map areas, Newfoundland. Geological Survey of Canada, Memoir 327, 184 pages.

Kennedy, M.J. and McGonigal, M.H.
1972: The Gander Lake and Davidsville Groups of northeastern Newfoundland: new data and geotectonic implications. Canadian Journal of Earth Sciences, Volume 9, pages 452-459.

McGonigal, M.H.
1973: The Gander and Davidsville Groups: major tectonostratigraphic units in the Gander Lake area, Newfoundland. M.Sc. Thesis, Memorial University of Newfoundland, St. John's, 121 pages.

Miller, H.G.
In preparation: Geophysical interpretation of the geology of the northeast Gander Terrane, Newfoundland.

O'Neill, P.P.
1987: Geology of the west half of the Weir's Pond (2E/1) map area. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 271-281.

Pettijohn, F.J., Potter, P.E. and Siever, R.
1973: Sand and sandstone. Springer Verlag, 618 pages.

Reinson, G.E.
1984: Barrier island and associated strandplain systems. *In* Facies Models, 2nd edition. *Edited by* R.G. Walker. Geoscience Canada, Report Series 1, pages 119-140.

Stouge, S.
1979: Conodonts from Davidsville Group of the Botwood Zone, Newfoundland. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 79-1, pages 43-44.

Tunbridge, I.P.
1981: Sandy, high energy flood sedimentation—some criteria for recognition with an example from the Devonian of southwest England. Sedimentary Geology, Volume 28, pages 79-95.

Walker, R.G.
1984: Shelf and shallow marine sands. *In* Facies Models, 2nd edition. *Edited by* R.G. Walker, Geoscience Canada, Report Series 1, pages 141-170.

Williams, H.
1968: Wesleyville, Newfoundland. Geological Survey of Canada, Map 1227A.

1976: Tectonostratigraphic subdivision of the Appalachian Orogen. Geological Society of America, northeastern section. Abstracts with programs, Volume 8, No. 2, pages 300.

Winkler, H.G.F.
1979: Petrogenesis of metamorphic rocks. Fifth Edition, Springer-Verlag, New York, 348 pages.

Wonderley, P.F. and Neuman, R.B.
1984: The Indian Bay formation: fossiliferous Early Ordovician volcanogenic rocks in the northern Gander Terrane, Newfoundland, and their regional significance. Canadian Journal of Earth Science, Volume 21, pages 525-532.

Current Research (1988) Newfoundland Department of Mines.
Mineral Development Division, Report 88-1, pages 177-182

ORDOVICIAN BIOSTRATIGRAPHIC STUDIES IN THE CENTRAL MOBILE BELT AND THEIR IMPLICATIONS FOR NEWFOUNDLAND TECTONICS

W.D. Boyce, J.S. Ash , P. O'Neill and I. Knight
Newfoundland Mapping Section

ABSTRACT

Trilobites have been recovered for the first time near Weir's Pond in the Davidsville Group. The faunas range in age from Late Arenig to Early Llandeilo. Poorly preserved graptolites have also been found at Weir's Pond.

Trilobite faunal distributions do not support McKerrow and Cocks' (1977, 1978, 1980, 1981, 1986) contention that the Reach Fault represents the suture along which the Iapetus Ocean closed.

INTRODUCTION

Hoping to clarify and refine age relations in central Newfoundland, B. Kean and P. O'Neill (Newfoundland Department of Mines) requested biostratigraphic assistance in the Long Island, Indian Bay Big Pond and Weir's Pond areas (Figure 1). In accedance with this request, trilobites were discovered at three localities during the course of field work.

BIOSTRATIGRAPHIC INVESTIGATIONS

Dunnage Zone

Weir's Pond (NTS area 2E/1). Three new trilobite localities were discovered within the Davidsville Group in the vicinity of Weir's Pond. An argillaceous sandstone outcrop containing the brachiopod *Orthambonites* was discovered in 1986 by O'Neill (1987, page 277) south-southwest of Weir's Pond. In 1987, the rocks at this locality yielded an abundant brachiopod fauna. The trilobite *Annamitella* sp. cf. *A. insulana* Dean was also discovered. The brachiopod and trilobite fauna appears comparable to the Late Arenig–Early Llanvirn faunas of the Summerford Group on New World Island (Dean, 1973) and that of the Indian Bay Formation of the Indian Bay Big Pond area (Wonderley and Neuman, 1984).

Jenness (1958, 1963) was the first to report fossils from Weir's Pond. He collected articulate and inarticulate brachiopods from two limestone exposures on the northwest side of the lake. He assigned the rocks an Ordovician age.

Williams (1972) also obtained fossil material from the Weir's Pond localities. Bolton (*in* Williams, 1972, page 20) identified for him the following:

dolerorthid brachiopod impression
endocer(o)id(?) cephalopod structure
Maclurites sp. aff. *M. speciosa* (Billings)

Blackwood (1978) subsequently revisited the two exposures, which yielded articulate brachiopods and gastropods. He also collected samples for conodont analysis. From the stratigraphically lower northern locality the following gastropods were collected:

Maclurea speciosa Billings
Pararaphistoma

The two gastropod taxa were identified by Yochelson (*in* Blackwood, 1978, page 75), who assigned them a late Early Ordovician to early Middle Ordovician age. From the stratigraphically higher southern locality the brachiopod *Orthambonites* was collected. The brachiopod was identified by Neuman (*in* Blackwood, 1978, page 75), who assigned it an Early Ordovician to early Middle Ordovician age.

The definitive age determination for the Weir's Pond exposures was provided by Stouge (1979, 1980a,b), who analyzed the conodont samples collected by Blackwood (1978). Stouge found that both localities had essentially identical North Atlantic conodont faunas and assigned the rocks a Late Llanvirn to Early Llandeilo (Chazy) age.

In 1982, S.P. Colman-Sadd (Newfoundland Department of Mines) and R.B. Neuman (Smithsonian Institution) collected more brachiopods from the southern Weir's Pond locality. The following genera were identified (R.B. Neuman, written communication to S.P. Colman-Sadd and W.D. Boyce, June 30, 1987):

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

[1] Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland, A1B 3X5

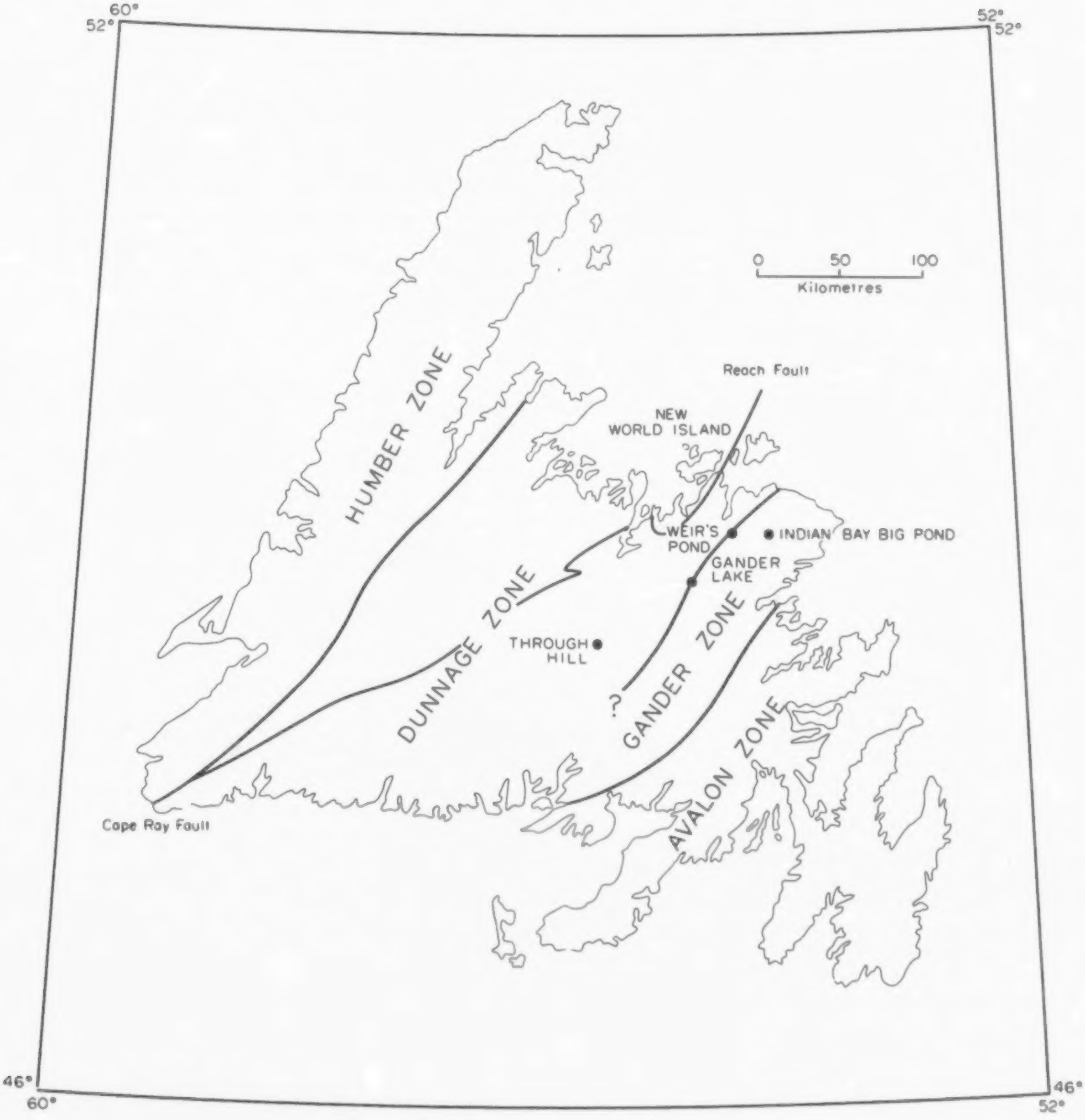

60°
52°
52°
52°
46°
60°
46°
52°
0
50
100
Kilometres
Reach Fault
NEW WORLD ISLAND
HUMBER ZONE
DUNNAGE ZONE
GANDER ZONE
AVALON ZONE
WEIR'S POND
INDIAN BAY BIG POND
GANDER LAKE
THROUGH HILL
?
Cape Ray Fault

Figure 1. *Trilobite collection areas discussed in this report. The location of McKerrow and Cocks' (1977) proposed Iapetus suture (Cape Ray Fault–Reach Fault) is also indicated.*

Orthambonites
Chaulistomella
Platystrophia
Eremotoechia
Atelesma
Leptaena

In 1987, I. Knight discovered trilobites at the southern Weir's Pond locality. Bioclastic limestone stratigraphically overlying the brachiopod-rich layer yielded the following trilobites:

Annamitella sp. undet.
Geragnostus/Trinodus sp. undet.
Hyboaspis sp. cf. *H. depressa* Raymond
Illaenus sp. undet.

Hyboaspis depressa Raymond occurs in the uppermost Day Point and basal Valcour formations of the Chazy Group of New York State (Shaw, 1968, page 63). Therefore, according to the correlation chart of Ross *et al.* (1982), *Hyboaspis* is strictly a Llandeilo genus. The Chazy Group as a whole is Late Whiterock (formerly Chazy), Late Llanvirn–Early Caradoc in age (Ross *et al.*, 1982; Shaw, 1968; Shaw and Fortey, 1977).

The presence of *Hyboaspis* sp. cf. *H. depressa* Raymond and the generic composition of the Weir's Pond fauna indicates a correlation with the Late Llanvirn–Early Llandeilo (Chazy) faunas of the Spruce Brook Formation in the Through Hill area (Boyce, 1987) and the Cobbs Arm Limestone of New World Island (Dean, 1971). The trilobite age determination supports the previous conodont (Stouge, 1979, 1980a,b) and brachiopod (R.B. Neuman, personal communication, 1987) age determinations.

Deformed shales and slates of the Davidsville Group, stratigraphically above the bioclastic limestone at Weir's Pond, contain abundant graptolites. These fossils were first reported from here by Williams (1972, page 20) and were later mentioned again by Dean (1978, pages 124, 203). Erdtmann (*in* Williams, 1972, page 20) identified the following species:

Climacograptus sp. cf. *C. scharenbergi* Lapworth
Climacograptus sp.
Orthograptus sp. cf. *O. calcaratus grandis* Ross and Berry
Orthograptus sp. cf. *O. quadrimucronatus* (Hall)

According to Dean (1978, page 124), this graptolite assemblage is Middle Caradoc (probably *Diplograptus multidens* Zone) in age.

S.P. Colman-Sadd obtained more graptolites from Weir's Pond in 1982. D. Boyce and J. Ash subsequently collected additional specimens from the lakeshore in 1985 and 1987. This material is currently being investigated by S.H. Williams (Memorial University of Newfoundland).

P. O'Neill also discovered a fossiliferous, pyrite-rich Davidsville limestone boulder close to outcrop in the vicinity of Weir's Pond. The boulder yielded the trilobite *Annamitella* and a gastropod. No brachiopods were recovered. The age, based solely on the occurrence of *Annamitella*, is Late Arenig to Early Llandeilo. However, the gastropod is identical to one of the species that occurs at the northern Weir's Pond fossil locality, reported by Yochelson (*in* Blackwood, 1978). The probable age of the limestone is therefore Late Llanvirn–Early Llandeilo.

Long Island (NTS area 2E/12). Strong and Kean (1972) documented cephalopods, conulariids, crinoids and ostracodes from the Cutwell Group on Long Island. The fossils came from beds and pockets of limestone associated with pillow lavas and pyroclastic rocks. A Middle Ordovician age was tentatively suggested for the Cutwell Group there.

In 1987, D. Boyce and B. Kean revisited the fossil localities of Strong and Kean (1972). Unfortunately, there were no new macrofossil finds either there or in roadside exposures in the area. However, five (5) samples were taken for conodont analysis.

Gander Zone

Indian Bay Big Pond (NTS area 2E/1). P. O'Neill obtained more brachiopod and trilobite material from argillaceous tuffs in the Indian Bay Formation of the Indian Bay Big Pond area. His collections, which Boyce is studying, augment those of Wonderley and Neuman (1984) and Boyce (1987). The new material is probably the best preserved of all the collections. Unfortunately, like the others, it was obtained from talus. However, O'Neill believes the talus is very close to outcrop because it is restricted to the north and south shores of Indian Bay Big Pond along regional strike. *Annamitella* remains the only trilobite recorded from Indian Bay Big Pond.

The *Annamitella* from Indian Bay Big Pond closely resembles *Annamitella insulana* Dean. This Late Arenig–Early Llanvirn species was originally described by Dean (1973) from the middle volcanic unit (Unit B) of the Summerford Group (Horne, 1970) exposed at Virgin Arm, New World Island (NTS area 2E/10).

REGIONAL SIGNIFICANCE OF LATE ARENIG–EARLY LLANVIRN AND LATE LLANVIRN–EARLY LLANDEILO TRILOBITE FAUNAS IN CENTRAL NEWFOUNDLAND

Faunal Provincialism

Late Arenig–Early Llanvirn trilobite faunas in central Newfoundland are known mainly from argillaceous tuffs and sandstones. These faunas are of mixed North American and Baltoscandian (European) aspect (Bruton and Harper, 1985) and are typically dominated by the nearly cosmopolitan leiostegiid genus *Annamitella*. Rich brachiopod faunas indicative of the Celtic Faunal Province (Williams, 1973; Neuman, 1976, 1984) are characteristically associated with these trilobite faunas (Bruton and Harper, 1985).

The Late Arenig–Early Llanvirn *Annamitella* fauna is widespread in central Newfoundland. It is known from the following areas:

1) Gander Lake–Davidsville Group (Jenness, 1958, 1963; McKerrow and Cocks, 1977);

2) New World Island–Unit B, Summerford Group (Dean, 1973; Neuman, 1976; McKerrow and Cocks, 1981);

3) Indian Bay Big Pond–Indian Bay Formation (Wonderley and Neuman, 1984; Boyce, 1987; this report); and

4) South-southwest of Weirs Pond–Davidsville Group (this report).

The Late Llanvirn–Early Llandeilo (Chazy) trilobite faunas of central Newfoundland typically occur in limestones. These faunas display strong North American affinities, although minor Baltoscandian elements are present. The cosmopolitan agnostid genera *Geragnostus/Trinodus* and the North American illaenid genus *Illaenus* predominate. Rich conodont faunas characteristic of the North Atlantic Faunal Province (Barnes *et al.*, 1973; Bergström, 1973) typically accompany these trilobite faunas (Stouge, 1979, 1980a,b,c).

The Late Llanvirn–Early Llandeilo (Chazy) fauna seems to be less widespread in central Newfoundland than the older *Annamitella* fauna. However, it is recognized in the following areas:

1) New World Island–Cobbs Arm Limestone, Summerford Group (Dean, 1971; Bergström *et al.*, 1974; McKerrow and Cocks, 1977);

2) Through Hill–Spruce Brook Formation (Boyce, 1987); and

3) Weir's Pond–Davidsville Group (this report).

Paleontological Controls on Structural Models

McKerrow and Cocks (1977, 1978, 1980, 1981, 1986) have long maintained that the Reach Fault, in central Newfoundland, represents the suture where the Iapetus Ocean closed. McKerrow and Cocks (1977, page 488) stated, 'This suture can be recognized by three types of evidence:

1. fundamental faunal differences over a long period of time;

2. ophiolitic suites and overlying deep-water sediments;

3. calc-alkaline igneous suites, which are characteristic of areas (adjacent to the old oceans) above subducting oceanic crust.'

McKerrow and Cocks (1977) compared the Late Arenig–Early Llanvirn *Annamitella* fauna of the Davidsville Group (east of the Reach Fault) to the Late Llanvirn–Early Llandeilo (Chazy) fauna of the Cobbs Arm Limestone (west of the fault). Because the two faunas are markedly different they assumed that each side of the fault belonged to different faunal provinces and crustal plates from the Late Arenig onward. This assumption has been the cornerstone of their hypothesis. However, faunas of different ages on either side of the fault were compared, rather than faunas of the same age, thus their assumption is unfounded.

Stouge (1979, 1980a,b,c) subsequently documented essentially identical Late Llanvirn–Early Llandeilo North Atlantic conodont faunas from either side of the Reach Fault. These faunas came from limestones of the Cobbs Arm Limestone on New World Island and the Davidsville Group at Weir's Pond. McKerrow and Cocks (1980) maintained that conodonts were strictly pelagic organisms and dismissed Stouge's results. They ignored the findings of Barnes and Fahraeus (1975) who demonstrated that most conodonts were probably benthic or nektobenthic.

The discovery of undeniably benthic trilobite faunas east of the Reach Fault (Boyce, 1987; this report) now enables the comparison of Late Arenig–Early Llanvirn and Late Llanvirn–Early Llandeilo (Chazy) faunas on either side.

Late Arenig–Early Llanvirn rocks on both sides of the Reach Fault are dominated by the trilobite *Annamitella*. This genus is known from three areas east of the fault, i.e., Gander Lake, Indian Bay Big Pond and immediately south-southwest of Weir's Pond. West of the fault, it occurs on New World Island. McKerrow and Cocks (1977, page 494) emphasized the apparent lack of *Annamitella* west of the Reach Fault. However, Dean (1973) had earlier described *Annamitella insulana* Dean from the Summerford Group of New World Island.

Late Llanvirn–Early Llandeilo (Chazy) trilobites of dominantly North American affinity are now known from east of the Reach Fault. They occur in limestones of the Spruce Brook Formation in the Through Hill area (Boyce, 1987) and the Davidsville Group at Weir's Pond (this report). These new faunas favorably compare with that described by Dean (1971) from the Cobbs Arm Limestone of New World Island, immediately west of the Reach Fault.

CONCLUSIONS

When trilobite (and conodont) faunas of the same age on opposite sides of the Reach Fault are compared, there is no contrast in their faunal provinciality. Consequently, faunal evidence cannot be used to support McKerrow and Cocks' (1977, 1978, 1980, 1981, 1986) contention that the Reach Fault represents the suture along which the Iapetus Ocean closed. In any event, as Stouge (1980c, page 1600) correctly emphasized, distribution of faunal provinces cannot be used as evidence for plate boundaries. Taylor (1976, 1977) demonstrated the coexistence of two contrasting Late Cambrian trilobite faunal provinces on the same continental plate and related it to contrasting water temperatures and depths. Furthermore, if the entire Dunnage Zone is allochthonous, as Colman-Sadd and Swinden (1984) have suggested, any suture is bound to lie beneath it and not be exposed at the surface.

ACKNOWLEDGMENTS

B. Kean is thanked for an educational and enjoyable introduction to the geology of Long Island. Dr. R.B. Neuman (Smithsonian Institution) is gratefully acknowledged for his continuing identification of our brachiopods. S.P. Colman-Sadd, W.L. Dickson and S.J. O'Brien critically reviewed the manuscript.

REFERENCES

Barnes, C.R. and Fahraeus, L.E.
1975: Provinces, communities and the proposed nektobenthic habit of Ordovician conodontophorids. Lethaia, Volume 8, pages 133-149.

Barnes, C.R., Rexroad, C.B. and Miller, J.F.
1973: Lower Paleozoic conodont provincialism. *In* Conodont Paleozoology. *Edited by* F.H.T. Rhodes. Geological Society of America, Special Paper 141, pages 156-190.

Bergström, S.M.
1973: Ordovician conodonts. *In* Atlas of Palaeobiogeography. *Edited by* A. Hallam. Elsevier, Amsterdam, London, New York, pages 47-58.

Bergström, S.M., Riva, J. and Kay, M.
1974: Significance of conodonts, graptolites, and shelly faunas from the Ordovician of western and north-central Newfoundland. Canadian Journal of Earth Sciences, Volume 11, pages 1625-1600.

Blackwood, R.F.
1978: Northeastern Gander Zone, Newfoundland. *In* Report of Activities for 1977. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 72-79.

Boyce, W.D.
1987: Cambrian-Ordovician trilobite biostratigraphy in central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 335-341.

Bruton, D.L. and Harper, D.A.T
1985: Early Ordovician (Arenig–Llanvirn) faunas from oceanic islands in the Appalachian–Caledonide orogen. *In* The Caledonide Orogen–Scandinavia and related areas. *Edited by* D.G. Gee and B.A. Sturt. John Wiley and Sons Limited, pages 359-368.

Colman-Sadd, S.P. and Swinden, H.S.
1984: A tectonic window in Newfoundland? Geological evidence that the Appalachian Dunnage Zone may be allochthonous. Canadian Journal of Earth Sciences, Volume 21, pages 1349-1367.

Dean, P.L.
1978: The volcanic stratigraphy and metallogeny of Notre Dame Bay, Newfoundland. Memorial University of Newfoundland, Geology Report 7, 205 pages.

Dean, W.T.
1971: Ordovician trilobites from the Central Volcanic Mobile Belt at New World Island, northeastern Newfoundland. Geological Survey of Canada, Bulletin 210, 37 pages.

1973: Lower Ordovician trilobites from the Summerford Group at Virgin Arm, New World Island, northeastern Newfoundland. Geological Survey of Canada, Bulletin 240, 43 pages.

Horne, G.S.
1970: Complex volcanic-sedimentary patterns in the Magog belt of northeastern Newfoundland. Geological Society of America Bulletin, Volume 81, pages 1767-1788.

Jenness, S.E.
1958: Geology of the Gander River ultrabasic belt, Newfoundland. Geological Survey of Newfoundland, Report 11, 58 pages.

1963: Terra Nova and Bonavista map-areas, Newfoundland. Geological Survey of Canada, Memoir 327, 184 pages.

McKerrow, W.S. and Cocks, L.R.M.
1977: The location of the Iapetus Ocean suture in Newfoundland. Canadian Journal of Earth Sciences, Volume 14, pages 488-495.

1978: A lower Paleozoic trench-fill sequence, New World Island, Newfoundland. Geological Society of America Bulletin, Volume 89, pages 1121-1132.

1980: Conodonts from the Davidsville Group, northeastern Newfoundland: Discussion. Canadian Journal of Earth Sciences, Volume 17, page 1599.

1981: Stratigraphy of eastern Bay of Exploits, Newfoundland. Canadian Journal of Earth Sciences, Volume 18, pages 751-764.

1986: Oceans, island arcs and olistostromes: the use of fossils in distinguishing sutures, terranes and environments around the Iapetus Ocean. Journal of the Geological Society of London, Volume 143, pages 185-191.

Neuman, R.B.
1976: Early Ordovician (late Arenig) brachiopods from Virgin Arm, New World Island, Newfoundland. Geological Survey of Canada, Bulletin 261, pages 11-61.

1984: Geology and paleobiology of islands in the Ordovician Iapetus Ocean: review and implications. Geological Society of America Bulletin, Volume 95, pages 1188-1201.

O'Neill, P.
1987: Geology of the west half of the Weir's Pond (2E/1) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 271-281.

Ross, R.J., Jr., Adler, F.J., Amsden, T.W., Bergström, D., Bergström, S.M., Carter, C., Churkin, M., Cressman, E.A., Derby, J.R., Dutro, J.T. Jr., Ethington, R.L., Finney, S.C., Fisher, D.W., Fisher, J.H., Harris, A.G., Hintze, L.F., Ketner, K.B., Kolata, D.L., Landing, E., Neuman, R.B., Sweet, W.C., Pojeta, J. Jr., Potter, A.W., Rader, E.K., Repetski, J.E., Shaver, R.H., Thompson, T.L. and Webers, G.F.
1982: The Ordovician System in the United States—correlation chart and explanatory notes. International Union of Geological Sciences, Publication Number 12, 73 pages.

Shaw, F.C.
1968: Early Middle Ordovician trilobites of New York. New York State Museum and Science Services, Memoir 17, 163 pages.

Shaw, F.C. and Fortey, R.A.
1977: Middle Ordovician facies and faunas in N America. Geological Magazine, Volume 114, pages 409-443.

Stouge, S.
1979: Conodonts from Davidsville Group of the Botwood Zone, Newfoundland. *In* Report of Activities for 1978. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 79-1, pages 43-44.

1980a: Lower and Middle Ordovician conodonts from central Newfoundland and their correlatives in western Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-1, pages 134-142.

1980b: Conodonts from the Davidsville Group, northeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 17, pages 268-272.

1980c: Conodonts from the Davidsville Group, northeastern Newfoundland: Reply. Canadian Journal of Earth Sciences, Volume 17, pages 1600-1601.

Strong, D.F. and Kean, B.R.
1972: New fossil localities in the Lush's Bight Terrane of central Newfoundland. Canadian Journal of Earth Sciences, Volume 9, pages 1572-1576.

Taylor, M.E.
1976: Indigenous and redeposited trilobites from Late Cambrian basinal environments of central Nevada. Journal of Paleontology, Volume 50, pages 668-700.

1977: Late Cambrian of western North America: trilobite biofacies, environmental significance and biostratigraphic implications. *In* Concepts and Methods of Biostratigraphy. *Edited by* E.G. Kauffman and J.E. Hazel. Dowden, Hutchinson and Ross Incorporated, Stroudsburg, pages 397-425.

Williams, A.
1973: Distribution of brachiopod assemblages in relation to Ordovician palaeogeography. *In* Organisms and Continents through Time. *Edited by* N.F. Hughes. Special Papers in Palaeontology, Number 12, pages 241-269.

Williams, H.
1972: Stratigraphy of Botwood map area, northeastern Newfoundland. Geological Survey of Canada, Open File 113, 103 pages.

Wonderley, P.F. and Neuman, R.B.
1984: The Indian Bay Formation: Fossiliferous Early Ordovician volcanigenic rocks in the northern Gander Terrane, Newfoundland, and their regional significance. Canadian Journal of Earth Sciences, Volume 21, pages 525-532.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 183-188

MIDDLE ORDOVICIAN GRAPTOLITES FROM CENTRAL NEWFOUNDLAND

S. Henry Williams
Department of Earth Sciences
Memorial University of Newfoundland

ABSTRACT

The Middle Ordovician black shales of the Shoal Arm Formation and Lawrence Harbour Shale of central Newfoundland are well known for their rich and biostratigraphically useful graptolite fauna. The present study involves detailed systematic collecting and full taxonomic treatment of the assemblages. A new set of graptolite zones will be subsequently erected for the late Llandeilo to early Ashgill(?) argillites. Conodont collections from associated nodular limestones should permit integration of the scheme with the standard British Middle Ordovician chronostratigraphy.

Poorly preserved graptolites have been recovered from one locality in the Victoria Lake Group near Grand Falls and may suggest an early Llandeilo age. It is anticipated that other black shale units recorded previously as unfossiliferous or non-graptolitic will also yield graptolites useful in biostratigraphic correlation.

INTRODUCTION

The author commenced a study of graptolites from the Dunnage Zone of central Newfoundland in the summer of 1987. The project initially involved identification and systematic collection of relatively unbroken sections through the Lawrence Harbour Shale and Shoal Arm Formation, with detailed mapping and section measuring where necessary. This was followed by collecting from less complete, comparitive localities (Figure 1). Further aims include the location of graptolitic horizons within the Victoria Lake Group and possible recovery of biostratigraphically useful faunas from other 'non-graptolitic' or 'unfossiliferous' strata such as the Boones Point Complex of Notre Dame Bay.

LAWRENCE HARBOUR SHALE AND SHOAL ARM FORMATION

Previous Study

The ubiquitous Middle Ordovician black shale of Notre Dame Bay has been variously referred to as the 'Caradocian argillites' (e.g., Dean, 1979) and the Exploits Group (e.g., Erdtmann, 1976), but was first defined as the Shoal Arm Formation (Espenshade, 1937) and the Lawrence Harbour Shale (Heyl, 1936) and 'unnamed argillite' (Helwig, 1967, 1969) of the Exploits Group. Other lateral equivalents appear to include the Rodgers Cove Shale and Dark Hole Formation of New World Island and several other formations within Notre Dame Bay and the Gander Lake area (see Dean, 1979).

Graptolites have been widely collected from the shale for much of this century; early collections received published reviews by Schuchert and Dunbar (1934) and by Ruedemann (1947). A series of more recent studies was initiated by Helwig (1967, 1969) and Horne (1968). A thorough review of graptolite localities and their correlation was made by Bergström *et al.* (1974), but they failed to include any taxonomic descriptions or figures of graptolites and relied mainly on previous collections. The lack of systematic paleontological study was remedied in part by Erdtmann (1970, 1976), but this material was restricted both numerically and spatially and lacked critical, systematic collecting. Erdtmann attempted to 'force' the central Newfoundland succession into the 'standard' North American scheme (Berry, 1960; Ross and Berry, 1963; Riva, 1969, 1974) with limited success, and his revisions have not since been utilized. The most recent comprehensive review was by Dean (1979), who included zonal assemblages from numerous localities; his identifications were made primarily by Riva, with additional studies by Erdtmann, Skevington and Cumming.

Results

Inspection of the most important sections through the Middle Ordovician black shale (localities supplied by S. Swinden, P. Dean and J. Meyer) revealed their inadequacy with respect to employing ideal biostratigraphic procedures. The only two localities studied to date with any kind of coherent stratigraphy are those at Little Red Indian Falls on the Exploits River south of Badger (studied briefly by Erdtmann, 1976) and at Lawrence Harbour in Notre Dame Bay (Figure 1). Even at these localities the unit is badly deformed, the sections broken and generally, graptolites have suffered some degree of tectonic distortion.

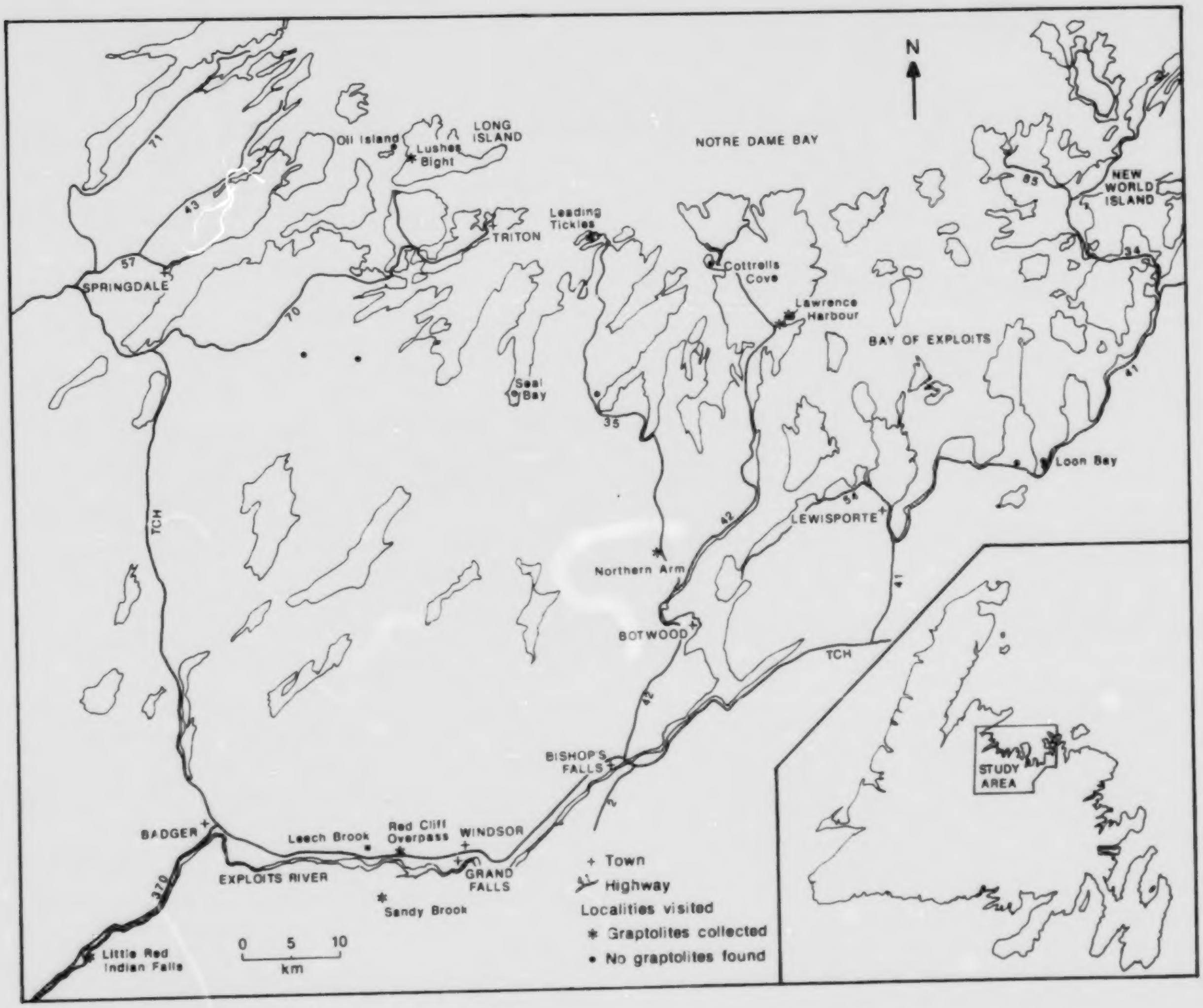

N
NOTRE DAME BAY
Oil Island
Lushes Bight
LONG ISLAND
NEW WORLD ISLAND
Leading Tickles
TRITON
SPRINGDALE
Cottrells Cove
Lawrence Harbour
BAY OF EXPLOITS
Seal Bay
Loon Bay
LEWISPORTE
Northern Arm
BOTWOOD
TCH
BISHOP'S FALLS
BADGER
Leech Brook
Red Cliff Overpass
WINDSOR
GRAND FALLS
EXPLOITS RIVER
Sandy Brook
Little Red Indian Falls
71
43
57
70
35
42
340
341
370
0 5 10
km
+ Town
Highway
Localities visited
* Graptolites collected
• No graptolites found
STUDY AREA

Figure 1. *Map of central Newfoundland showing localities visited during the summer of 1987.*

It is evident that no one section in central Newfoundland will yield a continuous stratigraphic succession spanning more than about one graptolite zone. Even cursory observation of samples while being collected in the field shows, however, that the currently employed division, merely borrowed from the British scheme, is unsuitable for Newfoundland and has diminished the quality of biostratigraphic resolution. Furthermore, the zones proposed by Erdtmann, based on a cursory look at the biostratigraphy, have proved unhelpful.

To improve the situation and permit stratigraphic refinement, a new graptolite zonal scheme will be erected for the region. Because of the lack of continuous, structurally simple sequences, a rather different approach will need to be employed from that used by the author elsewhere (e.g., Williams and Bruton, 1983). In order to erect a new set of zones, samples have been (and will be) collected from very narrow intervals up to only 10 cm thick in order to guard against any structurally induced mixing of graptolite taxa. Once all species have been identified, the many assemblages will then be compared and diagnostic zonal criteria developed using numerical computer analyses. These will be subsequently employed to erect a new biostratigraphy, which although never seen in any one section, should permit refined correlation and assist interpretation of regional data.

First inspection suggests that division into four or five zones will be possible, although a final decision must await study of both this and next summer's collections. For the purpose of this report, I include reference to four biostratigraphic intervals, informally termed zones 1 to 4. Zone 1 essentially correlates with the widespread *gracilis* Zone, yielding common *Nemagraptus gracilis* together with the latest species of *Didymograptus (Expansograptus)*. Zone 2 lacks *N. gracilis*, but has abundant *Climacograptus bicornis* and *Corynoides*. Zone 3 is characterized by *Climacograptus caudatus*, abundant *Dicellograptus pumilus* and *Climacograptus tubuliferus*. These zones are broadly equivalent to their British counterparts (*gracilis*, *multidens*, *clingani* and *linearis* zones respectively), and will almost certainly be revised before the completion of the present study.

It must be reiterated that use of the term 'Caradoc black shale' is inapt and should be discontinued. Based on correlations from outside Newfoundland, Zone 1 is at least partially Llandeilo in age, whereas Zone 4 (found in the 'unnamed argillite' of Helwig, 1967, equivalent to the basal Point Leamington Greywacke of Bergström *et al.*, 1974) may well be Ashgill (see Williams and Bruton, 1983; Williams, 1987). It is hoped that conodont collections from limestone nodules within the argillites will confirm correlation with the shelly-based British chronostratigraphy, and with that of North America.

Little Red Indian Falls. It was found necessary to make a detailed geological map at 1:200 using tape and compass in order to accurately locate graptolite samples and deduce the stratigraphy and structure (Figure 2). A gradational passage from greywacke through chert, and into black shale, occurs in the basal part of the section. It is presently unclear whether the greywackes belong to the Exploits Group or to the underlying Victoria Lake Group. The earliest graptolites found in siliceous shales overlying the chert belong to Zone 1 and are commonly well preserved, some horizons displaying three-dimensional, pyritized specimens. The top of the unit shows a gradational contact with the overlying greywacke; graptolites from this gradational passage indicate Zone 3. Unfortunately the stratigraphy between the base and top of the black shale appears incomplete, as at all other recorded localities. Approximately 30 precisely located graptolite collections were made, and several samples for conodont processing were taken from the basal greywacke–chert and from nodular limestone directly underlying the first thick greywacke bed in the upper part of the section.

Lawrence Harbour. Relatively well preserved and abundant graptolites may be collected, but this locality proved somewhat disappointing. No unbroken sections of any thickness occur, and although an approximate stratigraphy may be deduced, it is of limited potential for graptolite biostratigraphy. The lowest faunas as listed by previous authors belong to Zone 1 (Bergström *et al.*, 1974; Dean, 1979), and the latest graptolites from the transitional passage to greywacke are Zone 4 (i.e., later than at Little Red Indian Falls). No intervening zonal assemblages appear to be present in the harbour section, although the shale pit adjacent to the main road at Lawrence Harbour may show a transition to Zone 2. The latter locality yielded far better preserved material than the harbour section and has been mapped and sampled in detail. In addition, the author collected several samples for conodonts at Lawrence Harbour.

Other sections. Sections through Middle Ordovician black shale that yielded relatively good graptolites include the Red Cliff overpass section west of Grand Falls and Leading Tickles in Notre Dame Bay (Figure 1). The intervals yielding useful graptolites at these localities are, however, restricted to Zone 2? and Zone 3 respectively. A fairly rich, but badly deformed and weathered assemblage was collected from a roadcut just outside Northern Arm; the assemblage suggests a likely Zone 2 age. Many additional localities were inspected, but the vast majority were either highly cleaved or poorly fossiliferous.

Long Island–Oil Island, Notre Dame Bay. G. Dunning recently obtained a radiometric date suggesting a Llanvirn age for felsic volcanic rocks overlying a shale unit of supposedly Caradoc age (both belonging to the Cutwell Group) on Oil Island. The age of this latter unit was deduced by S. Swinden and others, due to a supposed correlation with a black shale on Long Island yielding '*gracilis* Zone' graptolites (Dean, 1979). Re-examination of Dean's faunal list does not, however, suggest a diagnostic zonal assemblage. Three exposures of black shale on Long Island were collected in conjunction with A. Sebinski. The fauna is sparse and of low diversity, although preliminary inspection does appear to confirm zones 1 or 2 (one species, however, seems to resemble a sinograptid, typical of Llanvirn and older strata). A visit to the shale on Oil Island immediately following the work on Long Island revealed a totally different lithology; that of Oil Island is much paler in colour, more siliceous, coarser grained and has common pyroclastic layers. Lithostratigraphic correlation with the black shale on Long Island is therefore unjustifiable. Because of its pale colour and presence of a well-developed cleavage, it is extremely unlikely that graptolites would be preserved within the shale on Oil Island. Two samples were collected from nodular limestones for conodont processing, which will hopefully confirm the unpublished 'Llanvirn' age deduced by C.R. Barnes based on a meagre conodont collection.

OTHER STRATIGRAPHIC UNITS

Results

Victoria Lake Group. Attempts to collect from this unit were largely thwarted by the perfect summer weather experienced throughout the field season, as forest areas were closed for all but a few days during this time. Two visits were, however, made to a section along Sandy Brook just below a dam, 12 km west-southwest of Grand Falls. One badly preserved, unidentifiable graptolite was recorded previously from this locality on the 1:50,000 Grand Falls geological map of Kean and Mercer (1981), but neither the exact bed nor identification exist. The exposure is an impressive but heavily faulted section through the Victoria Lake Group, here composed of volcaniclastic greywackes and dark to medium grey shale intervals up to 2 m thick. Unfortunately the ubiquitous cross-cutting cleavage rules out all the thicker shale units in terms of graptolite preservation. Following detailed bed-by-bed examination, a narrow, dark grey shale with cleavage running parallel to bedding was found on the second day, and a few badly deformed graptolites recovered. Preliminary study suggests a distinct similarity to '*Glyptograptus*' *teretiusculus*, a species characteristic of the early Llandeilo immediately preceding the *gracilis* Zone in

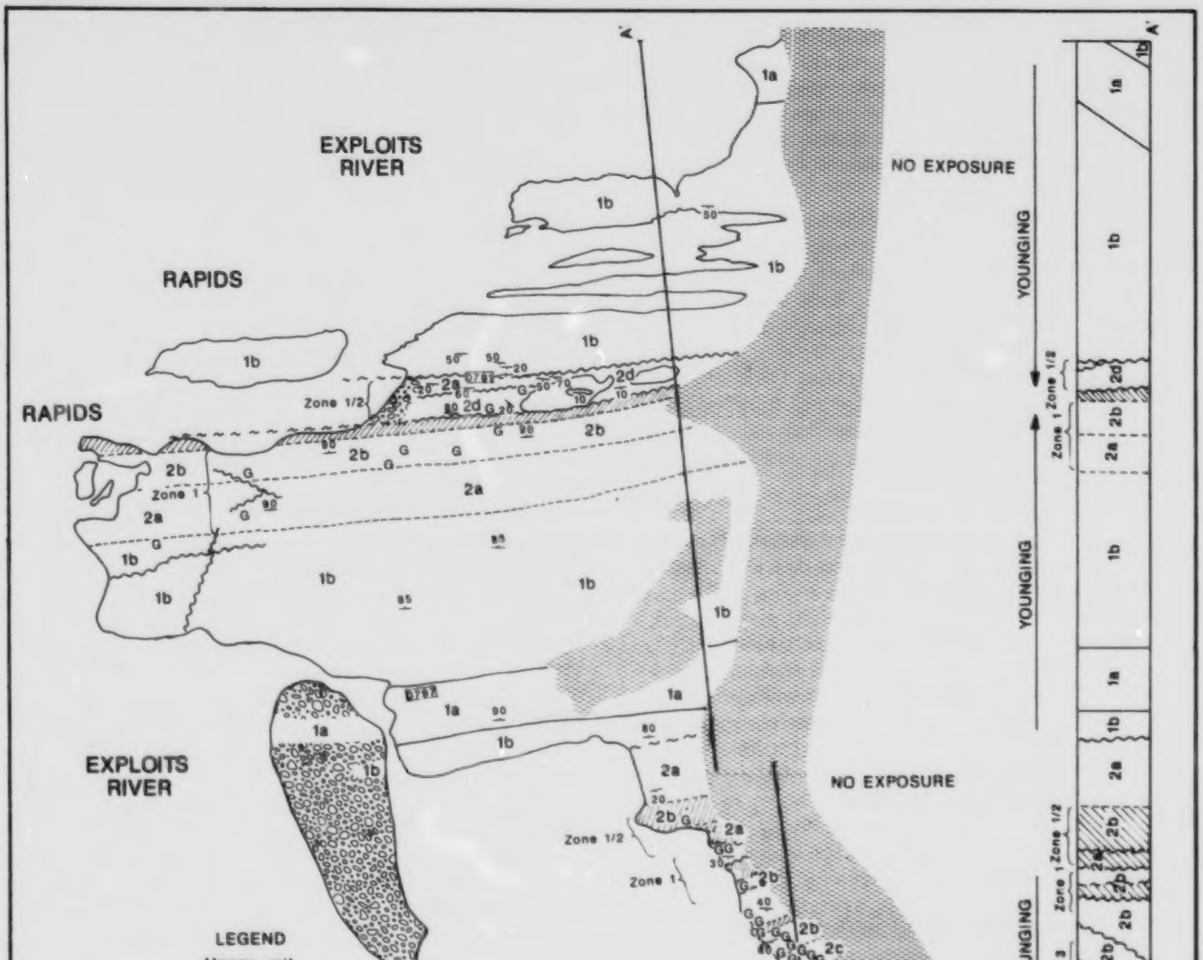

A'
EXPLOITS RIVER
RAPIDS
RAPIDS
EXPLOITS RIVER
NO EXPOSURE
NO EXPOSURE
NO EXPOSURE
1a
1b
2a
2b
2c
2d
3
G
Zone 1/2
Zone 1
Zone 3
A
TRUE NORTH
0 10 20
metres
YOUNGING
YOUNGING
YOUNGING
LEGEND
Upper unit
3 Greywacke
Middle unit
2d Massive dark grey silt and shale
2c Grey shale with subordinate black shale
2b Fissile black shale
2a Siliceous black shale
Lower unit
1b Chert
1a Greywacke
G Graptolite sample
J. Meyer locality no.
Lithological contact (sharp)
(gradational)
Fault (observed)
(inferred)
Sheared and tightly folded
Bedding dip (horizontal)
(inclined)
(vertical)
No exposure (river deposits)
(vegetation)

Figure 2: *Geological map and simplified cross section of Little Red Indian Falls, on the Exploits River 19 km southwest of Badger.*

Britain and Scandinavia. Should this identification prove correct, it would indicate little or no hiatus between the Victoria Lake Group and the overlying black shale. Recovery of additional graptolites bodes well for future age refinement of the Victoria Lake Group through utilization of this fossil group.

A drill core through supposed Victoria Lake Group from an old boring about 5 km south of the dam at Millertown (40 km southwest of Badger) was examined with abundant deformed graptolites including *Climacograptus bicornis*, *Dicellograptus salopiensis* and *Climacograptus brevis*. This assemblage demonstrates an unequivocal Zone 2 age, and indicates the presence of the Middle Ordovician black shale, rather than the Victoria Lake Group.

Wild Bight Group. S. Swinden guided myself and G. Dunning to an outcrop of shale on a small island in Seal Bay (Figure 1), where the lowest known rocks of the Wild Bight Group are exposed. Unfortunately the so-called 'black shale' is rather pale and cut obliquely by a strong cleavage; it is therefore very unlikely that graptolites are present.

Boones Point Complex. Brief inspection of the black shale matrix surrounding pillow lavas at Cottrells Cove, Notre Dame Bay, revealed a few silvery markings that almost certainly represent very poorly preserved graptolites. It is considered that further detailed investigation will probably lead to the discovery of graptolites, hopefully improving on the resolution of the 'Llanvirn' age suggested by rare conodonts in limestone blocks (see Swinden *et al.*, 1985).

ACKNOWLEDGMENTS

Financial assistance for the initial year of the project was given by Memorial University of Newfoundland through a President's NSERC Award, and fieldwork was supported by the Newfoundland Department of Mines. I also thank Paul Dean, Baxter Kean, Jamie Meyer, Scott Swinden and Adam Sebinski for guidance to localities, and my wife Kathleen Grebneff for help with mapping Little Red Indian Falls.

REFERENCES

Bergström, S.M., Riva, J. and Kay, M.
1974: Significance of conodonts, graptolites, and shelly faunas from the Ordovician of western and north-central Newfoundland. Canadian Journal of Earth Sciences, Volume 11, pages 1625-1660.

Berry, W.B.N.
1960: Graptolite faunas of the Marathon region, West Texas. Bureau of Economic Geology, University of Texas, Publication 6005, 179 pages.

Dean, P.L.
1979: The volcanic stratigraphy and metallogeny of Notre Dame Bay, Newfoundland. Memorial University of Newfoundland, Geology Report 7, 206 pages.

Erdtmann, B.-D.
1970: Morphometrie und computerstatistik am beispiel der graptolithengattung *Dicellograptus*. Neues Jahrbuch für Geologie und Paläontologie, Volume 134, pages 235-266.

1976: Die graptolithenfauna der Exploits Gruppe (Oberes Ordovizium, Caradoc) von zentral Newfoundland. Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg, Volume 45, pages 65-140.

Espenshade, G.H.
1937: Geology and mineral resources of the Pilley's Island area. Newfoundland Department of Natural Resources, Geology Section, Bulletin 6, 56 pages.

Helwig, J.A.
1967: Stratigraphy and structural history of the New Bay area, north central Newfoundland. Unpublished Ph.D. thesis, Columbia University, New York, 211 pages.

1969: Redefinition of Exploits Group, Lower Paleozoic, northeast Newfoundland. *In* North Atlantic Geology and Continental Drift. *Edited by* M. Kay. American Association of Petroleum Geologists, Memoir 12, pages 408-413.

Heyl, G.R.
1936: Geology and mineral deposits of the Bay of Exploits area. Geological Survey of Newfoundland, Bulletin 3, 66 pages.

Horne, G.S.
1968: Stratigraphy and structural geology of southwestern New World Island area, Newfoundland. Unpublished Ph.D. thesis, Columbia University, 280 pages.

Kean, B.F. and Mercer, N.L.
1981: Grand Falls map area (2D/13), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 8199 (with descriptive notes).

Riva, J.
1969: Middle and Upper Ordovician graptolites in the St. Lawrence Lowlands and of Anticosti Island. American Association of Petroleum Geologists, Memoir 12, pages 513-556.

1974: A revision of some graptolites from North America. Palaeontology, Volume 17, pages 1-40.

Ross, R.J. and Berry, W.B.N.
1963: Ordovician graptolites of the Basin Ranges in California, Nevada, Utah and Idaho. United States Geological Survey, Bulletin 1134, 177 pages.

Ruedemann, R.
1947: Graptolites of North America. Geological Society of America, Memoir 19, 652 pages.

Schuchert, C. and Dunbar, C.O.
1934: Stratigraphy of western Newfoundland. Geological Society of America, Memoir 1, 123 pages.

Swinden, S., Dean, P. and Meyer, J.
1985: Ordovician and Silurian volcanism and sedimentation in central Newfoundland. Geological Association of Canada, Newfoundland Section, Fall Field Trip Guide, 15 pages.

Williams, S.H.
1987: Upper Ordovician graptolites from the *D. complanatus* Zone of the Moffat and Girvan districts and their significance for correlation. Scottish Journal of Geology, Volume 23, pages 65-92.

Williams, S.H. and Bruton, D.L.
1983: The Caradoc-Ashgill boundary in the central Oslo Region and associated graptolite faunas. Norsk Geologisk Tidsskrift, Volume 63, pages 147-191.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 189-192

CONODONT AGES FOR THREE CARBONATE SAMPLES FROM MIDDLE ORDOVICIAN CHERTS AND SHALES IN CENTRAL NEWFOUNDLAND

J.R. Meyer, P.L. Dean[1], and C.R. Barnes[2]
Mineral Deposits Section

ABSTRACT

Conodonts have been recovered from three carbonate samples collected in 1981 during a lithogeochemical survey of Middle Ordovician cherts and shales from central Newfoundland. The faunas range in age from Middle Arenig to Middle Llanvirn.

INTRODUCTION

A lithogeochemical-sampling program was carried out in 1981 to assess the potential for sedimentary, clastic-hosted, base-metal sulphide deposits within Middle Ordovician cherts and shales in central Newfoundland (Dean and Meyer, 1982). These strata, which were deposited in a starved marine basin after the cessation of pre-Caradocian oceanic volcanic activity, are a widespread stratigraphic assemblage which can be recognized throughout central Newfoundland. The base of the sequence generally comprises thin- to thick-bedded chert overlying volcanic flows and volcaniclastic rocks. These cherts pass abruptly upward into black graptolitic shales, recording the effects of the Caradocian transgression (Leggett, 1978).

During the course of the sampling program, fossils were collected wherever possible, to help accurately date and correlate the strata. Graptolites were collected from black shales; carbonate beds, lenses and concretions were sampled for conodonts. In this paper we report the results of the conodont sampling.

METHODOLOGY

In the original study, stratigraphic mapping and sampling of the Middle Ordovician cherts and shales were carried out at twenty-four well-exposed coastal, road, and stream sections (Dean and Meyer, 1982). Mapping of the sections included a description of sedimentological and structural features, and mineral occurences. All samples were geochemically analyzed for major and trace elements, the results of which were reported in Dean and Meyer (1983). Thirteen carbonate rock samples from five sections, were collected for conodont analyses and submitted to Memorial University of Newfoundland. The samples were processed with acetic acid, and the insoluble residues separated by heavy liquid and then hand picked. Nine samples proved to be barren and one sample contained unidentifiable conodont fragments. The three productive samples containing identifiable conodont taxa, along with the sections from which they were sampled (Figure 1), are described below.

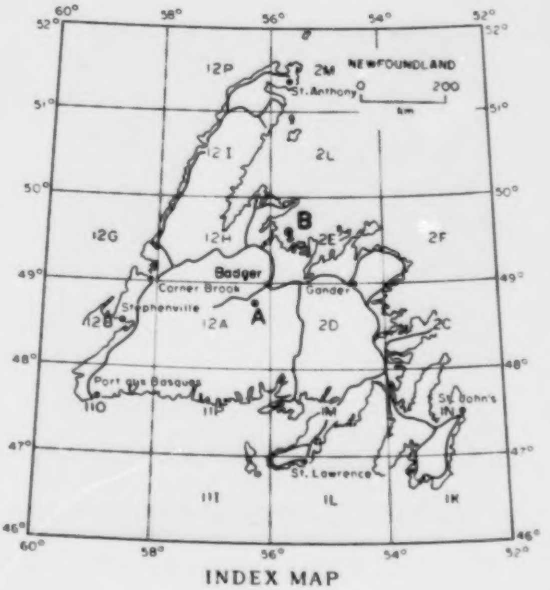


Figure 1. *Location of sections containing conodonts. (A) Little Red Indian Falls. (B) Oil Island and Lushes Bight sections.*

LITTLE RED INDIAN FALLS

A 124-m, steeply dipping, north-facing section of cherts and shales is exposed on the west side of the rapids at Little Red Indian Falls on the Exploits River, 19 km southwest of Badger (Figures 1 and 2). The base of the section is in fault contact with a northeast-striking syncline (within the same unit), and the top of the section is covered by Recent alluvium.

---

[1] Mineral Lands and Mines Division, Newfoundland Department of Mines

[2] Sedimentology and Marine Geoscience Branch, Geological Survey of Canada, 580 Booth Street, Ottawa, Ontario, K1A 0E8

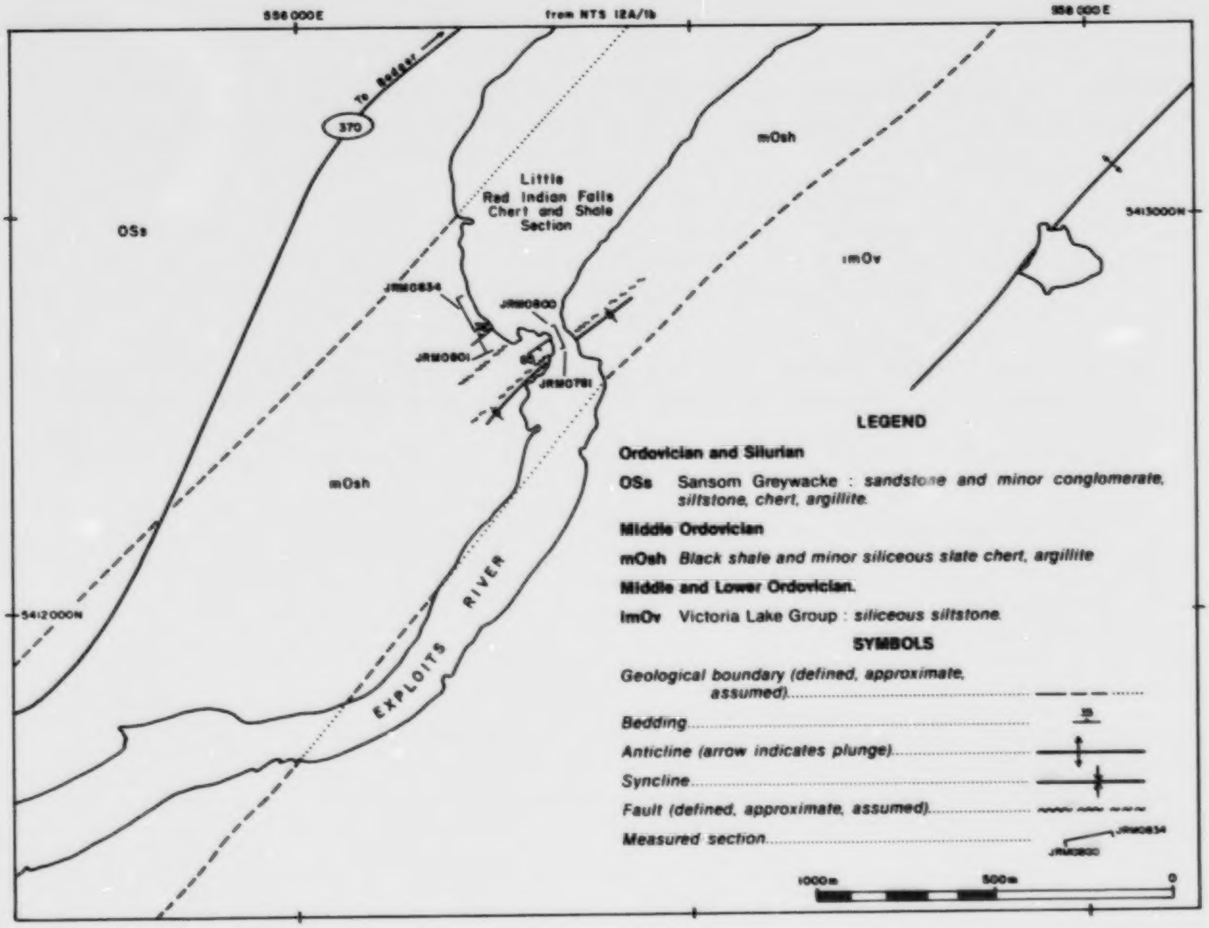

556 000E
from NTS 12A/1b
558 000E
5413000N
5412000N
To Badger
370
OSs
mOsh
lmOv
Little Red Indian Falls Chert and Shale Section
JRM0834
JRM0800
JRM0801
JRM0781
EXPLOITS RIVER
LEGEND
Ordovician and Silurian
OSs Sansom Greywacke : sandstone and minor conglomerate, siltstone, chert, argillite.
Middle Ordovician
mOsh Black shale and minor siliceous slate chert, argillite
Middle and Lower Ordovician
lmOv Victoria Lake Group : siliceous siltstone.
SYMBOLS
Geological boundary (defined, approximate, assumed)
Bedding
Anticline (arrow indicates plunge)
Syncline
Fault (defined, approximate, assumed)
Measured section
JRM0834
JRM0800
1000m
500m
0

Figure 2. *Location of Little Red Indian Falls section. (Geology after Kean and Jayasinghe, 1982).*

The lower half of the section consists of grey chert and minor shale, which forms a resistant ridge striking perpendicular to the falls (Figure 2; sample numbers JRM 781-800). Recessive black shale in the upper half is exposed below the falls (Figure 2; sample numbers JRM 0801-0834) and is extremely graptolitic, defining three graptolite zones that are approximately equivalent to the British *gracilis*, *multidens*, and *clingani* zones (Williams, *this volume)*.

Carbonate beds and lenses up to 5-cm thick, and concretions up to 50 cm in diameter, are present within both halves of the section, but are much more common in the lower cherty strata. The productive sample (JRM 0786) was collected 18 m above the base of the measured section. The host rocks consist of grey, thin-bedded argillaceous chert containing minor, very thin shale beds. Limestone was collected from a 2- to 8-cm-thick bed, which pinches and swells along strike. The following conodont taxa were identified from this sample:

Belodella sp.
Prioniodus (Baltoniodus) sp.

OIL ISLANDS

On the northeastern corner of the Oil Islands (Figure 3), at the head of Halls Bay, a 38-m section of calcareous shale and clastic limestone of the Parsons Point formation (Dean, 1978) is conformably overlain by felsic volcanics of the Long Tickle formation (Dean, 1978). This shale was correlated with other Carodocian shales around Notre Dame Bay (Dean, 1978). The base of the Oil Island section is not exposed.

The base of the section is on the northeastern edge of a wave-cut bench. Thin-bedded, calcareous shale and minor chert are folded and irregularly interbedded with medium- to coarse-grained clastic limestone and minor limestone conglomerate. Fifteen metres from the base of the section, a 10- to 15-m-thick massive unit of fine- to coarse-grained clastic limestone with an erosional base, contains blocks of shale up to 50 cm in size. The remainder of the section is thinly interbedded to massive, grey calcareous shale and limestone breccia.

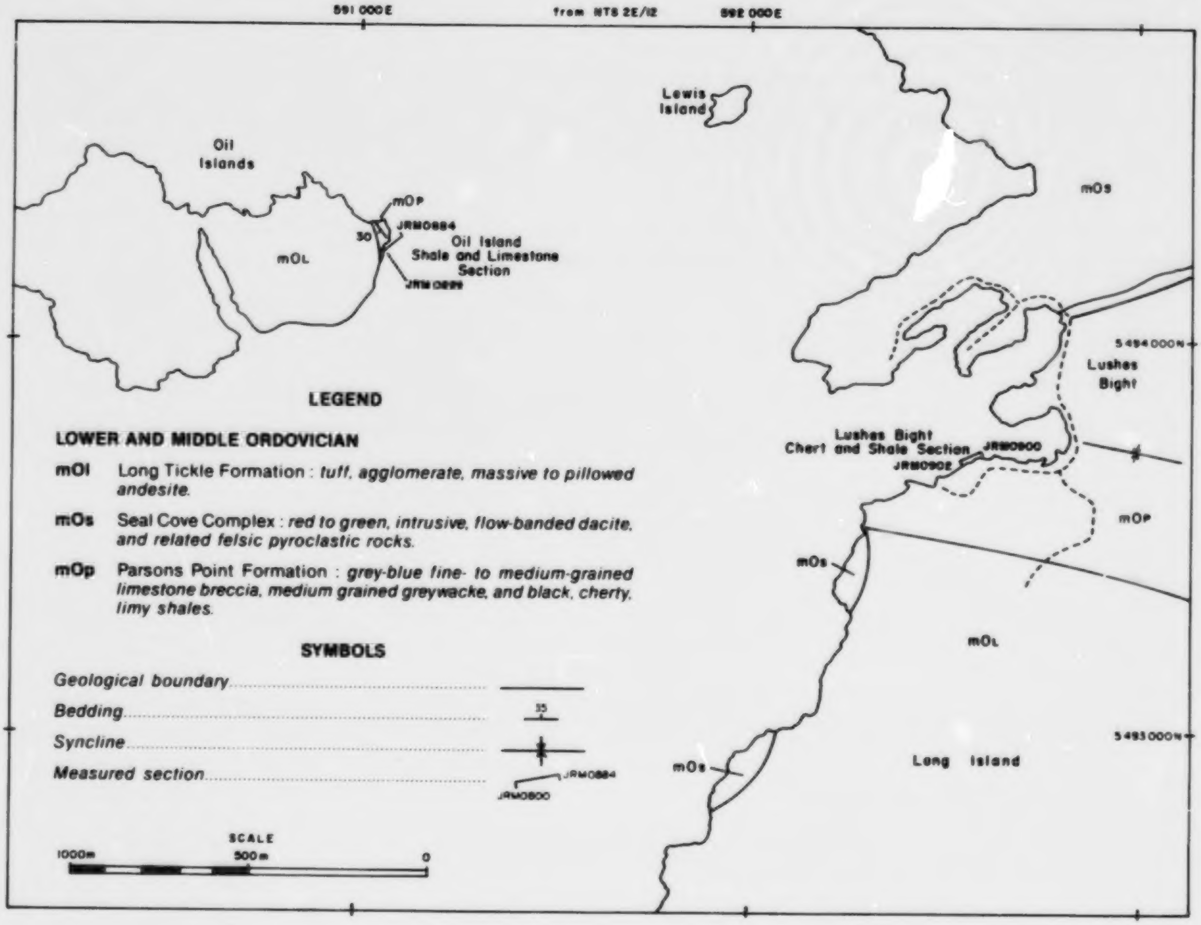

591 000E
from NTS 2E/12
592 000E
Lewis Island
Oil Islands
mOP
JRM0884
30
Oil Island Shale and Limestone Section
JRM0886
mOL
mOs
5494000N
Lushes Bight
Lushes Bight Chert and Shale Section
JRM0900
JRM0902
mOP
mOs
mOL
5493000N
Long Island
mOs
LEGEND
LOWER AND MIDDLE ORDOVICIAN
mOl Long Tickle Formation : tuff, agglomerate, massive to pillowed andesite.
mOs Seal Cove Complex : red to green, intrusive, flow-banded dacite, and related felsic pyroclastic rocks.
mOp Parsons Point Formation : grey-blue fine- to medium-grained limestone breccia, medium grained greywacke, and black, cherty, limy shales.
SYMBOLS
Geological boundary
Bedding
35
Syncline
Measured section
JRM0884
JRM0800
SCALE
1000m
500m
0

Figure 3. *Location of Oil Island and Lushes Bight sections. (Geology after Dean, 1978).*

Six limestone samples were collected from this section. The one sample that yielded conodonts (JRM 0886) was collected from a 3-m interval, 6 m from the base. The interval consists of thin-bedded, calcareous shale and thin beds and lenses of calcarenite and calcirudite. Importantly, from a biostratigraphic point of view, some of the lenses of calcarenite and calcirudite may have been transported downslope in the basin of deposition by mass flow processes (e.g., sliding). The conodont taxa recovered from this sample are:

Periodon aculeatus Hadding
Protopanderodus robustus (Hadding)
Prioniodus (Baltoniodus) prevariabilis medius Dzik

LUSHES BIGHT

On the western side of Long Island at Lushes Bight (Figure 3), argillaceous chert and shale of the Parsons Point formation are exposed on the south side of the harbour in 6- to 10-m cliffs, and on a wave-cut bench. The base of the 9-m section is not exposed, and the top is capped by a 2-m porphyritic dacite sill.

The section consists of thinly interbedded, argillaceous chert and shale, 1- to 4-cm thick and less than 5-mm thick, respectively. Graptolites have been recovered from this unit, (Dean, 1978), and are discussed by Williams *(this volume)*. Several 1- to 2-cm-thick sandy interbeds and grey calcareous concretions up to 15 cm in diameter are also present. These inconspicuous concretions (JRM 902) contain the most diverse conodont fauna of all three samples:

Belodella jemtlandica Löfgren
Belodella sp.
Cordylodus horridus Barnes and Poplawski
Paracordylodus gracilis Lindström
Periodon aculeatus Hadding
Prioniodus (Baltoniodus) prevariabilis medius Dzik
Protopanderodos rectus Lindström
Protopanderodos sp.

DISCUSSION

The conodont faunas in JRM 0786, JRM 0886, and JRM 0902 are similar, although JRM 0903 contains the most diverse fauna. *Prioniodus (Baltoniodus) prevariabilis medius* has arange of Lower to Middle Llanvirn in Sweden (Löfgren, 1978). *Belodella jemtlandica* has a similar range; both this species and *Periodon aculeatus* are first known in the latest Arenig. *Paracordylodus gracilis* is more typically found in the Arenig but it is usually a rare element. Current research on the Cow Head Group conodonts in western Newfoundland should firmly establish its range relative to the zonal taxa of conodonts and graptolites. *Cordylodus horridus* of Barnes and Poplawski (1973) is also characteristic of latest Arenig and Llanvirn strata. Löfgren (1978) reported *Protopanderodus rectus* to range into the Early Llanvirn in Sweden.

Based on the above comments, age assignments for these three samples are:

JRM 0786: Middle Arenig–Llanvirn
JRM 0886: Llanvirn, probably Early to Middle Llanvirn
JRM 0902: Llanvirn, probably Early to Middle Llanvirn.

The age given for the sample from Little Red Indian Falls (JRM 0786), based on fragmental and limited conodont data, has a wide range. An upper age limit for this section is provided by graptolites collected from black shales stratigraphically above, and in apparent conformable contact with, the chert unit containing the carbonate bed that yielded the conodonts (Williams, *this volume)*. The graptolites collected belong to Williams' Zone 1, the widespread *gracilis* Zone, of Middle Llandeilo to Lower Caradoc age.

COMMENTS

The most abundant and diverse fauna recovered from these samples came from the smallest sample of carbonate; namely, several clay-rich carbonate concretions 15 cm or less in diameter. This is in accord with Blome and Albert (1985), who cite carbonate concretions as being excellent places to preserve fossils, 'largely due to the rapid syngenetic formation at or near the sediment-water interface, which removes the fossil component from corrosive bottom waters relatively early and prevents crushing during compaction of sediments' (Blome and Albert, 1985). Furthermore, they state that large concretions tend to deform more than smaller ones, perhaps damaging brittle microfossils in the outer part, or, cracking and thus allowing penetration by 'destructive pore fluids'. The one sample submitted that contained unidentifiable conodont fragments, was collected from the outer part of a concretion 1 m in diameter, and samples from other, equally large concretions, proved to be barren. Blome and Albert (1985) suggest that the centre of large concretions are more likely to preserve fossils.

There are varying amounts and sizes of carbonate concretions in many of the sections sampled in the original survey (Dean and Meyer, 1982). These concretions, and those in other sections of fine grained sedimentary rocks, would seem to provide excellent sites to sample in an effort to obtain additional paleontological data.

ACKNOWLEDGMENTS

Terry Rees is once again thanked for his help in collecting the original samples in 1981. Conodont processing and initial identification was carried out at Memorial University by F. O'Brien. S. Swinden and D. Boyce critically reviewed and improved the manuscript.

REFERENCES

Barnes, C.R. and Poplawski, M.L.S.
1973: Lower and Middle Ordovician conodonts from the Mystic Formation, Quebec, Canada. Journal of Paleontology, Volume 47, pages 760-790.

Blome, C.D. and Albert, N.R.
1985: Carbonate concretions: an ideal sedimentary host for microfossils. Geology, Volume 13, pages 212-215, March 1985.

Dean, P.L.
1978: The volcanic stratigraphy and metallogeny of Notre Dame Bay, Newfoundland. Memorial University of Newfoundland, Geology Report 7, 205 pages.

Dean, P.L. and Meyer, J.R.
1982: Metallogenic study of Mid-Ordovician cherts and shales of central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-1, pages 175-187.

1983: Lithogeochemistry of Mid-Ordovician cherts and shales of central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File Report (NFLD 1317).

Kean, B.F. and Jayasinghe, N.R.
1982: Geology of the Badger map area (12A/16), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-2, 37 pages.

Leggett, J. K.
1978: Eustacy and pelagic regimes in the Iapetus Ocean during the Ordovician and Silurian. Earth and Planetary Science Letters, 41, pages 163-169.

Löfgren, A.
1978: Arenigian and Llanvirnian conodonts from Jämtland, northern Sweden. Fossils and Strata, no. 13, 129 pages.

Williams, S.H.
This volume: Middle Ordovician graptolites from central Newfoundland.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 193-205

THE AVALONIAN GEOLOGY OF SOUTHWEST BONAVISTA BAY: PORTIONS OF THE ST. BRENDAN'S (2C/13) AND EASTPORT (2C/12) MAP AREAS

Sean J. O'Brien and Ian Knight
Newfoundland Mapping Section

ABSTRACT

The map area is situated at the northwest terminus of the Avalon Zone, where uppermost Precambrian Avalonian rocks are separated from adjacent Gander Zone rocks by the Dover Fault, a 1-km-wide ductile fault zone. Other northeast-trending faults divide the area underlain by Avalonian rocks into lithologically and structurally contrasting regions.

Stratified rocks west of the Bloody Reach fault comprise the Musgravetown Group, a sequence predominated by shallow marine to terrestrial sedimentary rocks, but also containing a major volcanic component. The group is divisable into four formations that form a conformable succession, approximately 3 km thick, of latest Precambrian and possibly earliest Cambrian age. The rocks are disposed in open, locally periclinal folds that are provisionally interpreted as younger than earliest Cambrian. To the west, the Musgravetown Group is in fault contact with a narrow band of schistose volcanic rocks that are part of the Love Cove Group. The pervasive fabric that these rocks carry intensifies westward to the Dover Fault, where the volcanic rocks are reduced to mylonite.

The area east of the Bloody Reach fault is underlain by the Love Cove Group, the conformably overlying Connecting Point Group, and a thin outlier of Musgravetown Group rocks. Volcanic rocks, which predominate in the lower 1 km of the combined succession, pass upward into 1.7 km of epiclastic sediments comprising the lower three units of the Connecting Point Group. A distinctive mixtite separates those rocks from an overlying, 3-km-thick sequence of shale and turbidite.

The Love Cove Group and the lower 2 km of the Connecting Point Group form an overturned, eastward-younging succession that occupies the western inverted limb of a regional syncline. The remainder of the Connecting Point Group is either openly folded or homoclinal. East of the Bloody Reach fault, the Musgravetown Group forms a moderately dipping, west-younging homocline, and is unconformable upon the Love Cove Group. Auriferous alteration zones within the Love Cove Group are spatially associated with faults and granitoid intrusions.

INTRODUCTION

This paper summarizes the geological history of the uppermost Precambrian, Avalonian rocks exposed in the St. Brendan's (2C/13) map area and in the north-central portion of the adjacent Eastport (2C/12) map area (Figure 1). The results summarized below are the outcome of continued mapping and detailed sedimentological logging by the authors in the southwest Bonavista Bay region in 1987. A more detailed discussion of the results of the sedimentological studies is presented in an accompanying paper by Knight and O'Brien *(this volume)*. Initial results of the 1986 program, together with a discussion of the stratigraphic and tectonic problems of the region, are published in O'Brien (1987).

The area is accessible by small boat from any of the coastal communities in the southwest part of Bonavista Bay. The nearest road links to the area are at the towns of Dover, Hare Bay and Burnside. The five communities on Cottel Island are linked by road and serviced by Provincial Department of Transportation ferry service between Burnside and Perry's Cove.

Rocks of dominantly late Precambrian age, which lie east of the Dover Fault in the Bonavista Bay region, represent the northern terminus of the Avalon Zone (Williams, 1976) or Avalon Terrane (Williams and Hatcher, 1983), the most extensive of the tectonostratigraphic divisions of the Appalachian Orogen. The study area offers a superbly exposed cross-section through the uppermost Precambrian Avalonian succession, extending 30 km eastward from the zone-bounding Dover Fault. The rocks of the St. Brendan's map area west of the Dover Fault are part of the Gander Zone (Williams, 1976) or Gander Terrane (Williams and Hatcher, 1983), and are not a focus of this study. Descriptions of the geology of that portion of the map area are given in Blackwood (1976, 1977).

The details of mapping studies previously undertaken in the map area are available in the following publications:

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

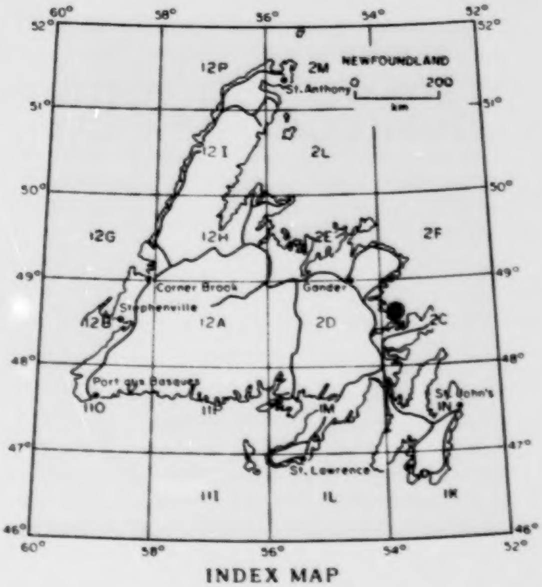


Figure 1. *Location of map area.*

Murray and Howley (1881), Hayes (1948), Widmer (1949), Christie (1950), Jenness (1963), Younce (1970), and Dalbello (1977). The reader is referred to O'Brien (1987) for details of these works that pertain to the regional geological setting.

Results of detailed structural analyses of the Dover Fault are presented in Blackwood and Kennedy (1975), Blackwood (1976, 1977), Dallmeyer *et al.* (1981) and Caron (1986).

GEOLOGY OF THE AVALONIAN ROCKS

The stratified rocks of the map area (Figure 2) comprise the northernmost exposures of the Love Cove (Jenness, 1963), Connecting Point (Hayes, 1948) and Musgravetown (Hayes, 1948) groups. These units consist of a variety of distinctive volcanic and sedimentary lithofacies, which are subdivided into 16 lithostratigraphic subunits that are mappable at 1:50,000 scale (O'Brien and Blackwood, 1987). The stratified rocks are intruded by plugs, dykes and sills of mafic and felsic composition.

The three major groups are essentially bounded by northeast-trending faults. In the west, the Dover Fault juxtaposes the more westerly of two belts of uppermost Precambrian Love Cove Group volcanic rocks with foliated granite and migmatite to the west (Blackwood, 1976, 1977). The eastern boundary of this belt of Love Cove Group rocks is the Howses Cove fault (Younce, 1970). This structure, and the Bloody Reach fault to the east, bound the main exposure area of the uppermost Precambrian Musgravetown Group. The latter unit contains the youngest rocks in the map area, which may be Tommotian (earliest Cambrian) in age; fossils have not been discovered in these rocks, therefore, this age assignment is provisional.

The Bloody Reach fault and another fault to the east, which trends northeastward through Cottel Island, delineate a second major belt of volcanic rocks. This belt includes the Love Cove Group, which here is intruded by granitoid rocks, and a thin succession of bimodal volcanic and red clastic rocks that is tentatively correlated with the lower portions of the Musgravetown Group to the west.

Rocks of the Connecting Point Group are exposed only to the east of the aforementioned fault through Cottel Island. This group conformably overlies the Love Cove Group and consists mainly of marine clastic sedimentary rocks.

Love Cove Group

The Love Cove Group is the oldest Avalonian stratigraphic element in the Bonavista Bay region (Jenness, 1963; Blackwood, 1976, 1977; O'Brien, 1987). In the northern Burin Peninsula, the group has been dated at 590 ± 30 Ma (Dallmeyer *et al.*, 1981a). Within the map area, rocks of this group lie in two geographically separate belts. The western belt constitutes the terminus of a 100-km-long, north-northeast-trending band of volcanic rocks that is bounded to the west, along its entire length, by the Dover Fault. The eastern belt, exposed in the core of a regional anticlinorium, is traceable continuously from the map area, southward through the type area at Clode Sound (Widmer, 1949) to the southern Burin Peninsula, (O'Brien *et al.*, 1977) for a total distance of 250 km.

Both belts are characterized, in most areas, by penetratively deformed volcanic rocks that are either vertical, steep upright or inverted. The Love Cove Group (Unit 1) in the map area has been subdivided into three assemblages of compositionally and texturally distinct lithofacies, corresponding to subunits 1a, 1b and 1c on Figure 2.

Subunit 1a underlies much of the western belt of the Love Cove Group, as well as the structurally lowest parts of the eastern belt. Its diagnostic lithology is schistose, sericitic, feldspar-rich, crystal and lithic tuff of intermediate to locally felsic and mafic composition (Plate 1). This rock type is associated with rhyolite flows, cherty tuff, coarse grained tuff-breccia and, in the area near Dover, volcanogenic sandstone. The contacts of this unit and others of the Love Cove Group are tectonic.

Subunit 1b is exposed only in the eastern belt. It includes variably foliated, mafic to intermediate, subaqueous flows, tuff and volcanic breccia. A particularly distinctive lithology, only locally developed, is a breccia with a shaly–mafic tuffaceous matrix. Two outcrops of this breccia contain recrystallized white marble clasts. The subunit's contacts are tectonic.

Subunit 1c is also exposed only in the eastern belt. It consists of approximately 800 m of intercalated felsic volcanic and shaly rocks that comprise the uppermost stratigraphic division of the Love Cove Group. The volcanic rock types within the subunit are variably schistose, vitric tuff, crystal

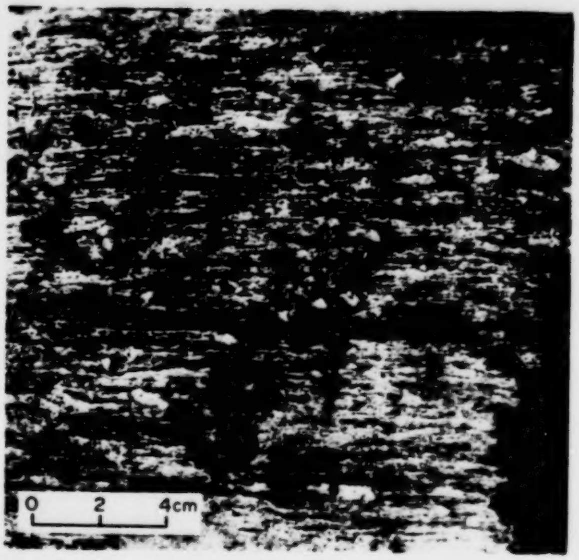


Plate 1. *Highly strained, schistose crystal–lithic tuff; subunit la is of the Love Cove Group near the Dover Fault.*

tuff, quartzphyric rhyolite, felsic agglomerate and sericite schist of volcanic protolith. These volcanic rocks occur as flows and pyroclastic layers between 1 m and several tens of metres thick, and are interstratified with grey to black shale that contain silicic laminae and thin chert beds.

The base of the Love Cove Group is not exposed. Approximately 1 km of section is exposed in the eastern belt. The maximum thickness of the Love Cove Group is unknown because its base is unexposed and internal contacts are tectonic.

Granitoids Intrusive into the Love Cove Group

Four small bodies of variably foliated, hornblende–biotite granodiorite (Unit 2) intrude the eastern belt of the Love Cove Group on the islands southwest of Cottel Island. The granodiorite is buff to grey, mainly fine grained and equigranular. It is cut by straight and irregularly bordered, fine grained diabase dykes, and contains cognate mafic inclusions that have irregular margins. The ferromagnesian minerals in the granodiorite are chloritized locally, and wispy veinlets and small pods of epidote are common features of the rock. These intrusions are brecciated, cleaved and increasingly finer grained at their margins, where screens of rhyolite and mafic volcanic rocks are preserved.

The pretectonic nature of the plutonic rocks of Unit 2, combined with their spatial association with the Precambrian Love Cove Group and the compositional similarity with dated (590 ± 30 Ma) Precambrian plutons within the Love Cove Group on the Burin Peninsula (Dallmeyer *et al.*, 1981a) are taken as indirect evidence of their Precambrian age and subvolcanic origin.

Connecting Point Group

The Connecting Point Group lies entirely to the east of, and conformably overlies, the Love Cove Group. Within the map area, the Connecting Point Group contains 10 lithofacies that comprise six lithostratigraphic units having a combined thickness of at least 3.5 km. The most complete stratigraphic section through that part of the group exposed in the map area occurs between Willis and Hail islands, on the overturned steep limb of a major syncline (Willis Reach syncline). The lower 1500 m of the group form an upward-coarsening stratigraphic succession, and consist of three lithostratigraphic divisions. Thin-bedded, green–grey and buff, tuffaceous sandstone and siltstone that contain intercalated black shale and pyroclastic rocks comprise Unit 3. It is succeeded conformably upward by Unit 4, a sequence of thick- to thin-bedded and amalgamated sandstone that locally contains thin-bedded, green–grey sandstone and shale intercalations (Plate 2). Grey–green to buff, thin-bedded sandstone, siltstone and shale, containing units of massive pebbly sandstone and black shale comprise Unit 5. The contact of Units 4 and 5 is gradational.

Plate 2. *Graded sandstone beds (Unit 4), Connecting Point Group; middle portion of lower bed contains coarser sand grains, suggesting beds are amalgamated. Note presence of small calcareous concretion (arrowed).*

Collectively, Units 3, 4 and 5 consist mainly of upward-coarsening megacycles of shale, thin-bedded mudstone and fine grained sandstone, thin- to thick-bedded, graded sandstone, and massive, pebbly and intraclastic coarse grained sandstone. The megasequence itself consists of 10-m-thick sequences that either coarsen and thicken upward (more common) or fine and thin upward (see Knight and O'Brien, *this volume*).

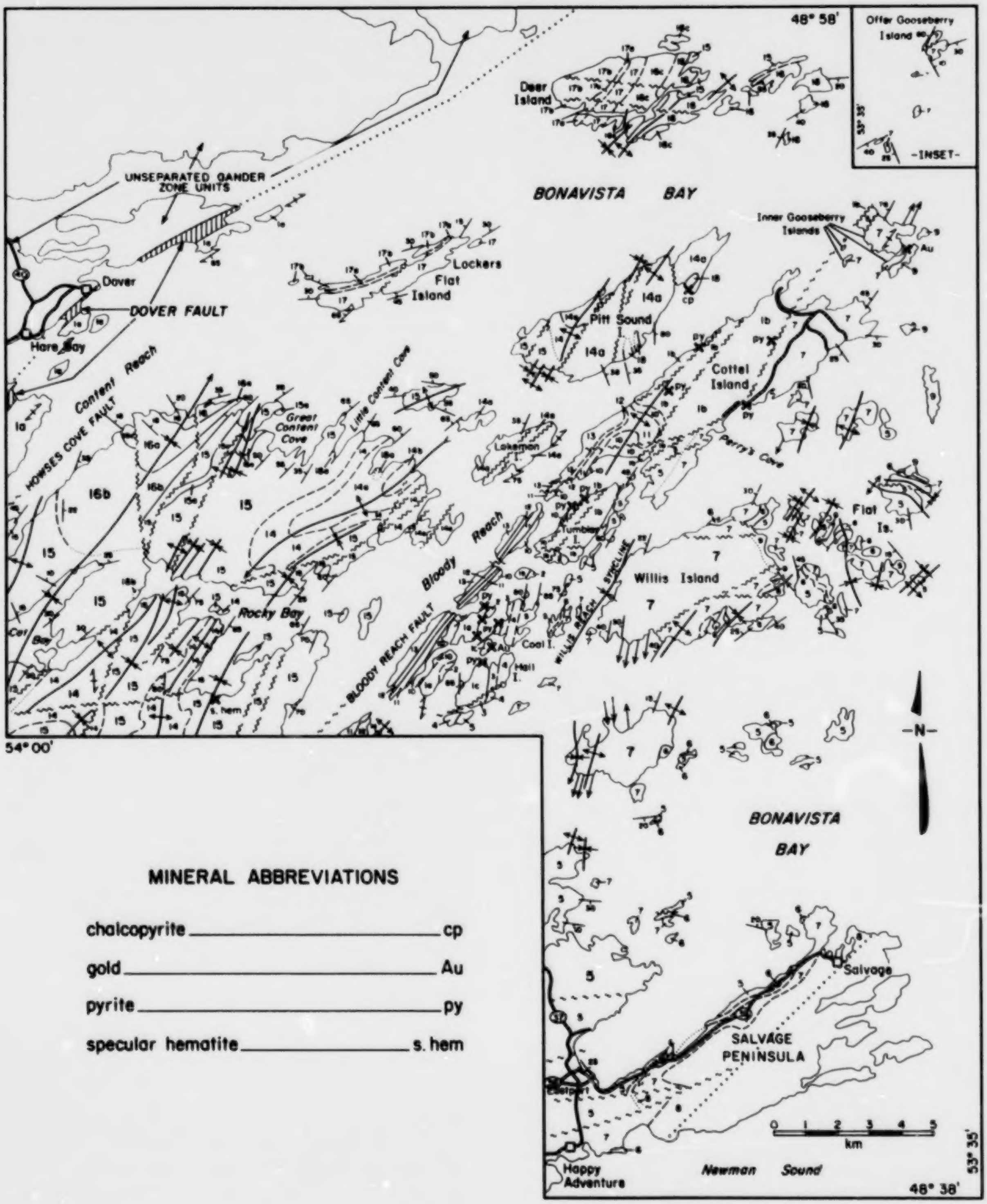

48° 58'
Offer Gooseberry Island
53° 35'
-INSET-
Deer Island
UNSEPARATED GANDER ZONE UNITS
BONAVISTA BAY
Inner Gooseberry Islands
Au
Lockers Flat Island
Dover
DOVER FAULT
Hare Bay
Pitt Sound I.
cp
Cottel Island
Content Reach
HOWSES COVE FAULT
Great Content Cove
Little Content Cove
Lakeman
Perry's Cove
Tumbler I.
Flat Is.
Bloody Reach
WILLIS REACH SYNCLINE
Willis Island
Rocky Bay
Cat Bay
BLOODY REACH FAULT
Coal I.
Hall I.
s. hem
py
54° 00'
-N-
BONAVISTA BAY
MINERAL ABBREVIATIONS
chalcopyrite — cp
gold — Au
pyrite — py
specular hematite — s. hem
Salvage
SALVAGE PENINSULA
Eastport
0 1 2 3 4 5
km
Happy Adventure
Newman Sound
53° 35'
48° 38'

Figure 2. *Avalonian geology of southwest Bonavista Bay; parts of 2C/12 and 2C/13.*

DEVONIAN OR OLDER

18 *Equigranular gabbro and diorite plugs, dykes and sills;* 18a: *granodiorite;* 18b: *granite porphyry*

UPPER PRECAMBRIAN TO LOWER CAMBRIAN

Musgravetown Group (Units 10–17)

DEER END FORMATION

17 *Green and grey sandstone and laminated siltstone, micaceous grey siltstone, quartz-rich sandstone, minor red sandstone and variegated siltstone (Deer Island);* 17a: *white and light grey, massive, planar stratified and cross-stratified quartz arenite and quartzofeldspathic sandstone; minor red sandstone locally;* 17b: *green and grey, locally buff sandstone and siltstone with calcareous nodules; light- and dark-grey shale*

UPPER PRECAMBRIAN

Musgravetown Group

CROWN HILL FORMATION

16 *Red sandstone and granule conglomerate;* 16a: *red boulder to pebble conglomerate;* 16b: *red and green sandstone and siltstone, minor granule to pebble conglomerate;* 16c: *mainly red and locally variegated sandstone, minor thin-bedded granule conglomerate and quartzose sandstone, green sandstone*

ROCKY HARBOUR FORMATION

15 *Green, wispy-laminated, wispy-bedded and planar stratified sandstone; minor green sandstone and pebble conglomerate;* 15a: *rhyolite flows and sills; thin monolithic aquagene mafic breccia unit near top at Deer Island*

BULL ARM FORMATION (Units 10–14: Unit 14 only occurs west of Bloody Reach Fault; Units 10 to 13 only occur east of Bloody Reach Fault.)

14 *Red, buff and grey, flow-banded rhyolite intercalated with minor ash-flow tuff and rhyolite breccia;* 14a: *interbedded green sandstone and basalt, green and grey tuffaceous sandstone and conglomerates;* 14b: *mafic agglomerate and volcanic breccia; minor unseparated gabbro sills*

13 *Red and maroon, granule and pebble conglomerate; red sandstone at base; minor red shale*

12 *Green tuffaceous sandstone*

11 *Vesicular basalt and minor mafic tuff and breccia; minor red sandstone*

10 *Red, flow-banded rhyolite containing tuff and breccia at base and top*

9 *Equigranular diorite and gabbro*

Connecting Point Group (Units 3–8)

8 *Black shale, thin-bedded argillite, silicified thin- to medium-bedded turbidite sandstone*

7 *Shale, thin-bedded sandstone and siltstone, and thick units of sandstone; planar stratified and slumped sandstone*

6 *Mixtite containing pebble and block-sized lithoclasts of sedimentary rocks together with mafic and felsic volcanic and plutonic detritus*

5 *Grey-green to buff, thin-bedded sandstone, siltstone and shale containing units of massive pebbly sandstone and black shale*

4 *Thick- to thin-bedded and amalgamated turbidite sandstone containing minor thin-bedded, green-grey sandstone and shale*

3 *Thin-bedded, green-grey and buff tuffaceous sandstone and siltstone; black shale; rare pyroclastic rocks*

2 *Buff to grey, equigranular hornblende–biotite granodiorite and granite*

Love Cove Group

1 1a: *Schistose lithic and crystal tuff, quartz porphyritic rhyolite, felsic agglomerate and sericite schist, minor cherty tuff and local volcanogenic sandstone;* 1b: *mafic to intermediate flows, tuffs and volcanic breccias; minor shaly matrix breccia; feldsparphyric tuff and breccia of intermediate composition;* 1c: *grey to black shale with silicic laminae, thin chert beds and fine grained tuff; intercalated rhyolite and breccia*

Geological boundary (defined, approximate, assumed, gradational)

Bedding, tops known (inclined, overturned)

Schistosity or foliation (inclined, vertical)

Lineation

Syncline (arrow indicates plunge direction)

Anticline (arrow indicates plunge direction)

Fault zone (Dover Fault)

Fault (defined, approximate, assumed)

Limit of mapping

Unit 6 is a spectacular mixtite deposit that occupies a stratigraphic position either equivalent to, or slightly younger than the top of the coarsening-upward succession described above. On the west limb of the Willis Reach syncline, the unit is quite thin. Superb outcrops of the mixtite occur to the east of the syncline axis, notably on Flat Islands, the west shore of Eastport Bay, and on many of the islands between these localities.

The mixtite contains pebbles and blocks of older units of the Connecting Point Group, as well as rarer volcanic and intrusive clasts of mafic to felsic composition, presumably derived from the underlying Love Cove Group (Plate 3). Sedimentary blocks are folded, internally slumped and display chaotic to oriented internal fabric (see Plate 12 of Knight and O'Brien, *this volume).* The matrix of the mixtite is characteristically black or grey, brown-weathering, granular to sandy mudstone. The mixtite is associated with amalgamated sandstone beds that are commonly slumped and convoluted, and locally intruded by mafic dykes prior to lithification.

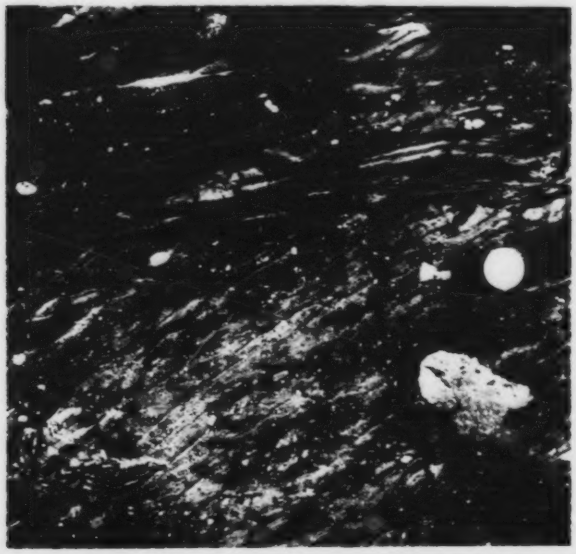


Plate 3. *Mixtite containing clasts of slumped siliceous argillite and rhyolite tuff in pebbly, granular mudstone matrix (Unit 6); Connecting Point Group. Canadian quarter for scale.*

That part of the Connecting Point Group directly above the mixtite is dominated by black and grey shale, grey–green, thin-bedded sandstone and siltstone, and thick units of thin-bedded and locally slumped sandstone (Unit 7; Plate 4). The shaly lithofacies are locally cut by synsedimentary mafic dykes similar to those that intrude Unit 6.

In the southeastern part of the area, the mixtite and overlying shale are succeeded by silicified, upward-coarsening megasequences of shale, turbidite sandstone and massive sandstone. These rocks, designated as Unit 8 on Figure 2, are well exposed on the Salvage Peninsula.

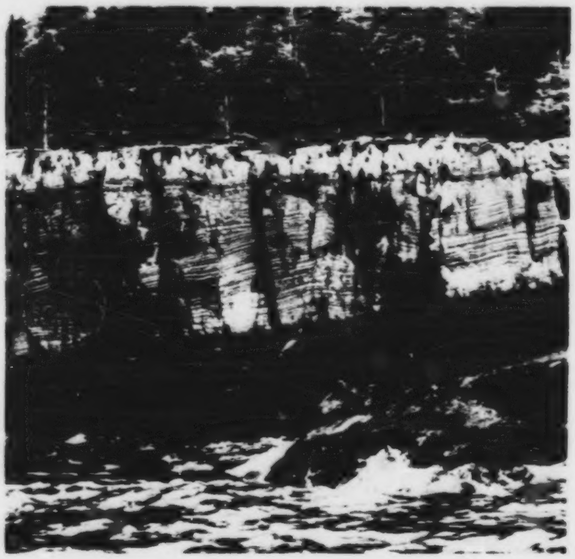


Plate 4. *Thick unit of thin-bedded, locally convoluted sandstone interbedded with shale (Unit 7); Connecting Point Group, Willis Island.*

The contact of the Connecting Point Group and the underlying Love Cove Group is exposed on the structurally inverted west limb of the Willis Reach syncline. At Hail Island and Coal Island, tuff and shale of subunit 1c of the Love Cove Group are intercalated with the lower 500 m of the Connecting Point Group. Elsewhere in the map area (e.g., Cottel Island, Tumbler Island) the contact is a fault.

Mafic Plutonic Rocks within the Connecting Point Group

The Connecting Point Group is intruded by a suite of pretectonic mafic sills, dykes and plugs (Unit 9) that outcrop in a broad zone that trends northeasterly across the central part of the Connecting Point Group outcrop belt. Most of the coarse grained plutonic rocks, particularly the plugs, are found in the northeast corner of the map area. The exact temporal relationship among the dykes, sills and plugs is not yet known, however, some of the mafic dykes are synsedimentary.

The diagnostic lithology of these intrusions is fine- to medium-grained, equigranular diorite; gabbro of similar texture is present locally. The rock is brown weathering, grey-green to dark green and contains rare mafic xenoliths 2 to 3 cm in diameter. The diorites are variably fractured and brecciated, and chlorite and epidote alteration is common. Near the contacts of the larger plugs, diorite is spatially associated, in places, with fine grained basalt porphyry.

Musgravetown Group

Within the map area, subaerial and subaqueous volcanic and sedimentary rocks of the Musgravetown Group outcrop in two areas, separated by the Bloody Reach fault. A thin, west-younging, north-northeast-striking bimodal volcanic succession, capped by red sedimentary rocks, is exposed east of the fault. This succession is continuous southward into the type area of the group at Musgravetown (Hayes, 1948). The western belt of dominantly clastic sedimentary rocks continues southwestward for 100 km, parallel to and in tectonic contact with the western belt of the Love Cove Group. The succession is subdivided into four units of formational status, following the nomenclature used previously to denote these rocks (e.g., Jenness, 1963; Younce, 1970; O'Brien, 1987). Both eastern and western belts are discussed separately as their exact stratigraphic relationship is uncertain (see below).

Eastern Belt. The Musgravetown Group east of the Bloody Reach fault is an approximately 800-m-thick homoclinal succession of mainly subaerial volcanic and sedimentary rocks (Units 10 to 13). The lowest unit in the sequence consists of approximately 200 m of red to maroon, variably banded, very fine grained rhyolite (Unit 10). Intricately flow-banded rhyolite forms 90 percent of the exposures of this unit; spherulitic zones are present, but uncommon. A buff, lithic-rich ash flow occurs locally at the base of the rhyolite; a distinctive rhyolite breccia forms the top of the unit.

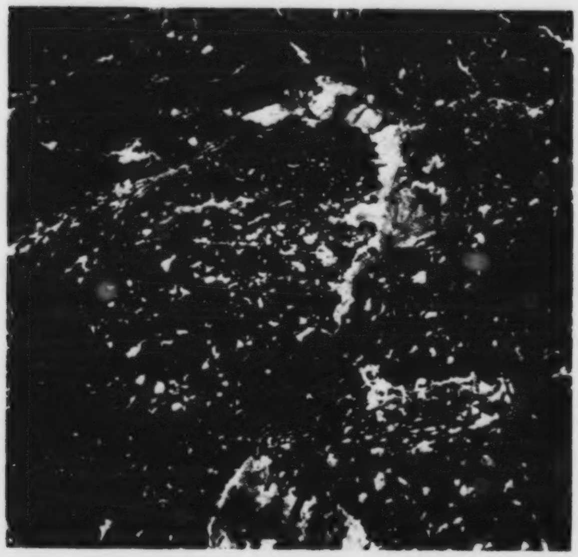


Plate 5. *Vesicular basalt with quartz–carbonate veinlets (Unit 11); Musgravetown Group, west shore of Bloody Reach.*

The rhyolite breccia is conformably overlain by approximately 225 m of basaltic volcanic rocks (Unit 11). The diagnostic lithology is amygdule-rich, variably oxidized basalt (Plate 5). The basalt is generally massive, although flow tops are recognized locally. Mafic tuff and thin beds of red sandstone are intercalated with the basalt in several places. The top of the unit is marked by a zone of flow-top breccia overlain by a coarse grained, epiclastic volcanic breccia containing subangular, rounded and tabular clasts of the basalt and underlying rhyolite.

The basalt unit is succeeded by approximately 50 m of thin-bedded to laminated, dark-green, locally tuffaceous sandstone (Unit 12). The basal contact of the sandstone is gradational over 2 to 3 m.

Unit 12 grades upward, over a few metres, into a coarsening-upward, 400-m-thick succession of dominantly red, coarse grained, clastic sedimentary rocks (Unit 13). Locally, a green–yellow, metre-thick, tuffaceous sandstone is present at the base of the succession. Above this sandstone, the lower part of the unit consists of graded and rippled, generally poorly bedded to amalgamated red sandstone containing thinly interstratified red shale. These rocks are succeeded by red, poorly sorted pebble conglomerate containing sandstone interlayers, which pass upward through interbedded red, pebble conglomerate, sandstone and rare shale into cleaved, pebble conglomerate. The latter rock is rich in rhyolitic volcanic detritus and persists to the top of the succession.

Plate 6. *Lithic tuff of Unit 10 overlying basalt–boulder conglomerate, Tumbler Island.*

The base of the Musgravetown Group east of the Bloody Reach fault is exposed on the west shore of Tumbler Island. There, a thin unit of lithic tuff, overlain by rhyolite, is unconformable on mafic volcanic rocks of the Love Cove Group. The two groups are separated by a 1- to 2-m oligomict, boulder conglomerate–breccia containing rounded blocks of the underlying mafic rocks (Plate 6).

Western Belt. The extensive Musgravetown Group succession west of the Bloody Reach fault is divided into four formations, which from oldest to youngest are: Bull Arm, Rocky Harbour and Crown Hill (Jenness, 1963) and Deer End (Younce, 1970).

The Bull Arm Formation (Unit 14) is composed of dominantly felsic volcanic and lesser tuffaceous sedimentary and mafic volcanic rocks that are exposed in a series of periclinal folds, mainly in the eastern half of the outcrop belt. Its diagnostic rocks are rhyolite flows and ash flows, both of which are flow layered. The rhyolite flows, like those in the Musgravetown Group to the east of the Bloody Reach fault, are characterized by their intricate flow patterns. Minor amounts of felsic volcanic breccia are associated with the flows. A sequence of green and grey, mafic tuffaceous sedimentary rocks (subunit 14a), containing several subaerial basalt flows, minor rhyolite flows and a distinctive mafic agglomerate (subunit 14b), underlies the main rhyolite unit in an anticlinal core located north of Rocky Bay and east of Great Content Cove (Figure 2).

Plate 7. *Wispy-bedded sandstone; Rocky Harbour Formation, Musgravetown Group.*

The stratigraphically highest rhyolite of the Bull Arm Formation is overlain by a pebble to cobble conglomerate unit that marks the base of the overlying and structurally concordant Rocky Harbour Formation (Unit 15). This formation is between 1- and 1.5-km thick in the map area and is divided into sedimentary and volcanic lithofacies. The most widespread rock type within the formation is green, thin-bedded to laminated, fine- and medium-grained sandstone, displaying a characteristic, wispy stratification (Plate 7). This rock is associated with planar-stratified and cross-stratified, locally quartzose, green, buff and pale-yellow sandstone, and minor pebble conglomerate. At least four separate rhyolite flows or sills (subunit 15a) are interstratified with the upper part of the sequence. These are either fine grained and originally glassy (now devitrified), very finely porphyritic or flow banded; all are buff to pale yellow-green.

The top of the Rocky Harbour Formation is drawn at the first appearance of purple and red sandstone interbeds of the overlying Crown Hill Formation (Unit 16). This formation consists of mainly red sandstone and pebble to boulder conglomerate and is separated into four informal lithostratigraphic units (Unit 16 and subunits 16a, 16b and 16c). The Crown Hill Formation is exposed in a broad open syncline on the east shore of Content Reach, and to the north, in open folds on Deer Island and nearby islands. All subunits are not necessarily exposed or deposited in a single area.

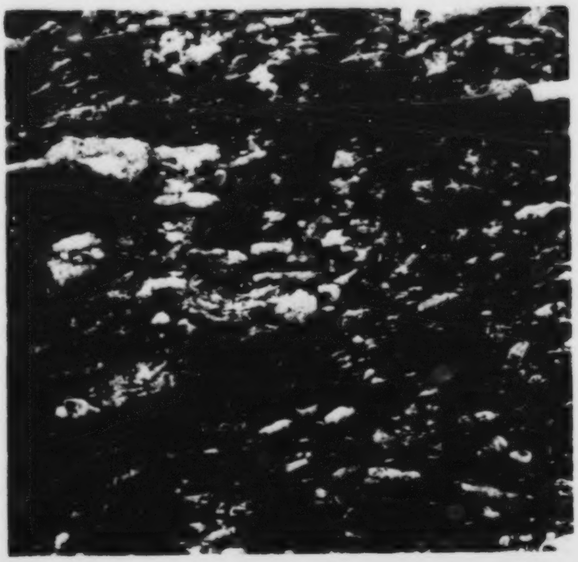


Plate 8. *Pebble conglomerate; Crown Hill Formation, Musgravetown Group from core of the syncline at Content Reach.*

At Deer Island, the base of the Crown Hill Formation is marked by red sandstone and granule conglomerate (Unit 16). In the syncline at Content Reach, red, purple and green sandstone, granule sandstone and granule to pebble conglomerate (subunit 16b) form the lowest part of the Crown Hill Formation. This is overlain by a fining-upward boulder to pebble conglomerate succession (subunit 16a; Plate 8). Clasts in these conglomerates are well-rounded, poorly sorted and derived from underlying Musgravetown Group rocks, particularly the Bull Arm Formation. The conglomerates fine rapidly along strike across the core of the syncline, and are succeeded by red sandstone and granule conglomerate, equivalent to the oldest part of the Crown Hill succession at Deer Island (Unit 16). At Deer Island, the uppermost subunit (16c) of the Crown Hill Formation is exposed. It consists of green sandstone, overlain by mainly red and also variegated sandstone that contains thin beds of granule conglomerate and quartzose sandstone.

At Deer Island, the Crown Hill Formation is overlain conformably by the Deer End formation (Unit 17; Younce, 1970), a unit consisting of approximately 900 m of green and grey sandstone, quartzite, quartz sandstone, grey shale and calcareous sandstone. A similar sequence occurs along strike to the southwest at Lockers Flat Island. That portion of the succession on Deer Island above the highest quartzitic sandstone was included in the Deer End formation by Younce (1970). Younce's original definition is here expanded to include that part of the succession below the quartzite to the top of the underlying Crown Hill Formation. The Deer End formation has not yielded body fossils, but it is lithologically similar to lowermost Cambrian rocks in Fortune Bay (e.g., Chapel Island Formation) that conformably underlie the Random Formation quartzites. The authors do not concur with Younce's assignment of the quartzitic portion of this succession to the Random Formation.

The basal unit of the Deer End formation consists of a thin succession of variegated sandstone and siltstone (exposed only on Deer Island), overlain by green and grey, thin- to medium-bedded sandstone and laminated siltstone containing S-shaped worm burrows. The green and grey rocks are interbedded with quartzose sandstone and grey siltstone, the latter being rich in detrital muscovite. These rocks are, in part, interstratified with, but also overlain by white, quartzofeldspathic sandstone and quartz arenite containing a minor amount of variegated sandstone. The top of the formation, exposed only on the west end of Deer Island, consists of green and grey sandstone with calcareous nodules, grey shale and calcareous sandstone. Younce (1970) measured this unit's total thickness at approximately 525 m.

An exact correlation between Musgravetown Group units on either side of the Bloody Reach Fault cannot be made without the results of chemical and precise geochronological studies, some of which are still in progress. The sequence east of the fault may represent: 1) a condensed version of the entire succession to the west, or 2) equivalents of the Bull Arm Formation only. The first scenario requires a thinning of the Rocky Harbour Formation from 1500 m in the west to 50 m in the east. The latter possibility is presently favoured.

Plutonic Rocks within the Musgravetown Group

Dykes and sills of mainly gabbroic composition intrude the Musgravetown Group. These are designated as Unit 18 on Figure 2. Many are demonstrably pretectonic. Several gabbros intruding into the lower portion of the group are exposed along the coastline between Content Reach and Bloody Reach and on Pitt Sound Island. Typically, a core of coarse- to medium-grained, patchy-textured, equigranular to subporphyritic gabbro fines outward into fine grained plagioclase-porphyritic diabase. Locally, the gabbro contains patches of quartz diorite. At Little Content Cove, cordierite-bearing, wispy-bedded sandstone is cut by chloritized, fine grained, porphyritic to subporphyritic hornblende–biotite granodiorite (subunit 18a), the contacts of which can be traced parallel to the strike of the sandstone. Many cleaved to massive diabase dykes, generally less than 1-m wide, intrude the Bull Arm and Rocky Harbour formations. Diabase dykes that intrude into higher levels of the succession are not common.

An orange-red granite porphyry sill or dyke (subunit 18b), containing zoned and hematitized feldspar phenocrysts up to 2-cm long, intrudes the upper part of the Rocky Harbour Formation at the east end of Rocky Bay. A dyke of similar composition and texture intrudes similar rocks on the west shore of Content Reach.

STRUCTURE

The map area is crossed by several major northeast- to north-northeast-trending, high-angle faults that define lithologically and structurally distinct regions. In the west, the Dover Fault separates the western belt of the Love Cove Group from mylonitic Dover Fault granite (Blackwood, 1976, 1977). In the western belt, the Love Cove Group carries a regionally penetrative, vertical to subvertical, northeast-trending foliation, which intensifies adjacent to the Dover Fault. Within the steep to vertical fault zone, tuffs are mylonitic. The Dover Fault has a protracted history of movement (Blackwood, 1976, 1977), although the mylonitic fabric developed within the fault zone is considered to be Acadian (Dallmeyer *et al.*, 1981). The main and perhaps latest movements are considered generally to be strike slip (Blackwood, 1977, 1985; Caron, 1986). These observations are supported by deep seismic data (Keen *et al.*, 1986), which indicate the structure is a vertical fault that offsets the Moho. A detailed description of the fault can be found in Blackwood (1976, 1977) and Dallmeyer *et al.*, (1981). Its kinematic history has been discussed by Caron (1986).

The Howses Cove fault (Younce, 1970) is a high-angle structure that separates the Love Cove Group from adjacent Musgravetown Group rocks to the east. The fault, unexposed in the map area, strikes north-northeast from Howses Cove in the adjacent Gambo (2D/16) map area under Content Reach. It juxtaposes highly strained, sericitized and chloritized, volcanic rock and openly folded, little-deformed rocks of the upper parts of the Musgravetown Group (Plate 9).

The folded Musgravetown Group to the west of the Bloody Reach Fault is cut by numerous northeast- and

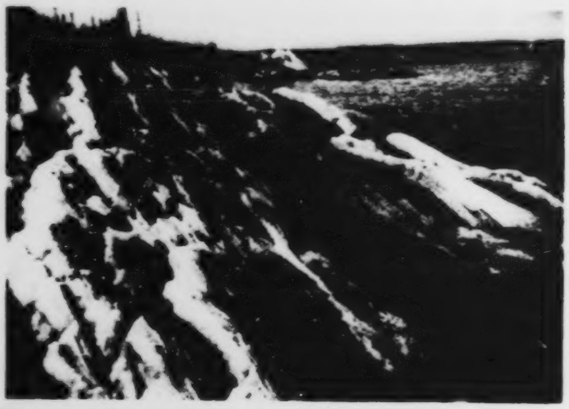


Plate 9. *Moderately dipping sandstone, typifying structural style in Musgravetown Group near trace of Howses Cove Fault; Dover Fault and Gander Zone are in background skyline.*

northeast-trending, high-angle faults and by east-southeast-trending cross faults. A major fault zone trending north-northeastward through Pitt Sound Island is marked by zones of sericite schist, brecciation and quartz veining.

The Bloody Reach fault is unexposed in the map area, but its trace underlies Bloody Reach; the geology of small islets within the reach (not shown on Figure 2) constrain the position of the fault to within 1 km of the eastern shore. On land to the southeast (outside the map area), the structure comprises a ductile fault zone in which strain is relatively high. The fault zone separates the Love Cove Group from the western belt of the Musgravetown Group (O'Brien, 1987).

The Musgravetown Group to the east of the Bloody Reach fault is offset sinistrally by cross faults that trend east-northeast, east and east-southeast.

The Love Cove Group and the lower parts of the Connecting Point Group are exposed on the common inverted limb of a major anticline–syncline pair, the axes of which trend northeastward through Hail Island and Willis Reach, respectively. Typically, the Connecting Point Group strata are steeply inverted or vertical and upright. On the east side of Cottel and Tumbler islands, however, inverted beds of Connecting Point Group having dips as shallow as 45 degrees are exposed. Within and to the east of the Willis Reach syncline, the Connecting Point Group is predominated by cleaved shaly rocks that are disposed in a series of small-scale, fold pairs with east-dipping axial planes. The stratigraphically higher levels of the group exposed east of Willis Island are disposed in broad, open, locally periclinal folds with partly curvilinear fold hinges. Farther south and east, on the Salvage Peninsula, the highest levels of the group form an east-dipping homocline.

The distribution of the lower portion of the Musgravetown Group, including much of the Bull Arm Formation and the lower half of the Rocky Harbour Formation, is controlled by several north-northeast-trending periclinal folds. A major open, south-plunging anticline controls the outcrop pattern of the lower part of the Bull Arm Formation. The regional disposition of the upper part of the Rocky Harbour Formation and the overlying Crown Hill and Deer End formations of the Musgravetown Group is controlled by a major, open, north-plunging syncline, the axis of which passes immediately west of Lockers Flat Island and Deer Island. Parasitic on the major regional fold are an open, gently north-plunging anticline to its west, and several open, south-plunging syncline–anticline pairs to its east.

The Musgravetown Group to the east of the Bloody Reach fault is disposed in a moderately (40 to 60 degrees) west-dipping homocline offset by cross faults. On the south end of Cottel Island, the succession is folded into a steeply plunging, periclinal anticline.

METAMORPHISM

All rocks within the map area contain mineral assemblages typical of low-grade, regional metamorphism. Whereas there is evidence for some synvolcanic metamorphism in the form of epidote–quartz blocks in intraflow basalt breccia, most of the chlorite-grade assemblages formed during the main episode of deformation. Typical macroscopic assemblages are quartz–sericite–epidote and chlorite–epidote–albite.

Pretectonic cordierite hornfels occur in the aureole of small intrusions in the Musgravetown and Connecting Point groups. Intrusion of the granodiorites into the Love Cove Group has resulted in local silicification, sericitization and epidotization.

ECONOMIC GEOLOGY

In the central portion of the map area, the Love Cove Group contains numerous occurrences of silicified and pyritized, locally sericitized volcanic rocks. Many of these showings have yielded elevated gold contents. The occurrences in the central St. Brendans map area form the northeast continuation of a narrow (1 to 2 km) band of variably altered, locally auriferous rocks within the Love Cove Group, extending along strike for over 30 km. All but three of the samples listed in Table 1 are assays of chip and grab samples collected within this zone.

In the St. Brendan's map area, altered volcanic rocks containing pyrite, sericite and secondary quartz, with or without gold, are exposed on Hail Island, Coal Island, the northeast end of Broad Island and several of the small islets adjacent to these islands, as well as on Tumbler Island and Cottel Island (see Figure 2). On the latter two islands, a several-hundred-metre-wide zone of pyritic alteration is developed within intermediate tuffs of the Love Cove Group. Mineralization is found in each of the three subunits of the Love Cove Group, and in several areas the mineralization and alteration is spatially associated with mafic dykes. These alteration zones are also spatially associated with fault zones and in some cases with exposed granitoid intrusions. The age of mineralization is unknown, although similar mineralization in the same rocks along strike on the Burin Peninsula is considered to be Precambrian (Huard and O'Driscoll, 1986).

The protolith of the altered rocks include vitric tuff, lithic tuff, quartz-phyric rhyolite, felsic agglomerate, mafic tuff and metabasic flows. Gold contents up to 575 ppb (1 m chip sample collected from a quartz vein in silicified rhyolite) were obtained during the course of mapping (Table 1). A typical silicified rock from the Coal Island–Hail Island area contains crosscutting, grey and black quartz veinlets and sweats (both mm- and cm-scale), as well as pervasive fine grained silica. The degree of pyritization of these rocks is variable. Individual occurrences may contain between 0.1 and 2 percent disseminated sulphide or cm-scale zones of massive pyrite. The degree of sericitic alteration varies from a fine dusting on cleavage planes to sericite schist composed almost entirely of fine grained mica.

The Musgravetown Group hosts minor mineral occurrences in several localities. On the north shore of a cove on the northwest corner of Pitt Sound Island, chalcopyrite,

Table 1. Gold assay results (greater or equal to 10 ppb) from the Love Cove Group in the St. Brendan's and Eastport map areas

Sample number	N.T.S.	Lithology	Au (ppb)	UTM easting,northing
1941383	2C/12	felsic tuff	32	287750,5394100
1941384	2C/12	felsic tuff	22	287750,5394100
1941389	2C/12	rhyolite	87	281675,5400750
1941402	2C/12	silicified tuff	21	288650,5398600
1941404	2C/12	silicified breccia	51	289250,5399375
1941405	2C/12	silicified tuff	80	289150,5399350
1941409	2C/12	silicified breccia	111	289200,5399350
1941415	2C/12	pyritic sericite schist	10	290900,5402700
1941416	2C/12	pyritic sericite schist	14	290900,5402700
1941556	2C/13	intermediate tuff	30	294500,5407200
1941561	2C/13	quartz veinlets	65	294500,5407000
1941562	2C/13	silicified tuff	10	294400,5406900
1941563	2C/13	silicified tuff	75	294360,5406780
1941572	2C/13	rhyolite	15	294380,5405010
1941575	2C/13	silicified tuff	10	295000,5406370
1941578	2C/13	silicified tuff	25	294650,5405880
1941583	2C/13	quartz vein	575	294610,5406000
1941619	2C/13	felsic dyke	45	286850,5405200
1941681	2C/13	quartz vein	510	308310,5417800
1941682	2C/13	quartz vein	65	308310,5417800

together with minor chalcocite and bornite, in quartz veins, occurs near the contact of a diorite–gabbro intrusion. At the showing, veinlets of granodiorite and felsite, presumably late-stage phases of the larger intrusion, crosscut a metabasalt that is part of a succession of interbedded basalt and tuffaceous sedimentary rocks within the Bull Arm Formation (subunit 14a). The showing consists of two quartz–carbonate–chlorite–epidote veins, approximately 10 cm wide, that trend north and dip between 70 degrees east and vertical. In the midnineteenth century, a small adit was driven into the vein for a distance of several metres (Plate 10). Massive veins and stringers of quartz, locally containing specular hematite and pyrite, cut the Musgravetown Group elsewhere on Pitt Sound Island as well as at The Beaches and Lakeman's Island. On the south shore of Rocky Bay, rusty, silicified zones cut by quartz–chlorite–epidote–specular hematite veins are present in the basal part of the Rocky Harbour Formation.

Plate 10. *Adit along chalcopyrite–bornite–calcite vein, Pitt Sound Island.*

The Connecting Point Group is cut by quartz–carbonate veins adjacent to the mafic plugs in the northeast part of the map area. On the southernmost of the three Inner Gooseberry Islands, a 70-m by 1- to 30-cm-crosscutting quartz vein occurring at the diorite–shale contact, yielded an assay of 510 ppb gold. Murray and Howley (1881) describe argentiferous quartz–asenopyrite–specularite–pyrite veinlets from the same area.

ACKNOWLEDGMENTS

The authors acknowledge the very capable boatmanship and cheerful assistance of Jacob Lushman and Irwin Wheaton. An early version of the manuscript was reviewed by B.H. O'Brien and P.P. O'Neill.

REFERENCES

Blackwood, R.F.
1976: The relationship between the Gander and Avalon Zones in the Bonavista Bay Region, Newfoundland. Unpublished M.Sc Thesis, Memorial University of Newfoundland, St. John's, 156 pages.

1977: Geology of the east half of the Gambo (2D/16) map area and the northwest portion of the St. Brendan's (2C/13) map area, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-5, 20 pages.

1985: Geology of the Facheux Bay area (11P/9), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-4, 56 pages.

Blackwood, R.F. and Kennedy, M.J.
1975: The Dover Fault: western boundary of the Avalon Zone in northeastern Newfoundland. Canadian Journal of Earth Sciences, Volume 12, pages 320-325.

Caron, A.
1986: Microstructural study of the Dover Fault, northeastern Newfoundland. *In* Program with Abstracts, Volume 11. Geological Association of Canada, Mineralogical Association of Canada and Canadian Geophysical Union, Joint Annual Meeting, Ottawa, page 52.

Christie, A.M.
1950: Geology of the Bonavista map area, Newfoundland. Geological Survey of Canada, Paper 50-7, 40 pages.

Dalbello, A.E.
1977: Stratigraphic position and petrochemistry of the Love Cove Group, Glovertown–Traytown map area, Bonavista Bay, Newfoundland, Canada. Unpublished M.Sc Thesis, Memorial University of Newfoundland, St. John's, 155 pages.

Dallmeyer, R.D., Blackwood, R.F. and Odom, A.L.
1981: Age and origin of the Dover Fault: tectonic boundary between the Gander and Avalon Zones of the northeast Newfoundland Appalachians. Canadian Journal of Earth Sciences, Volume 18, pages 1431-1442.

Dallmeyer, R.D., Odom, A.L., O'Driscoll, C.F. and Hussey, E.M.
1981a: Geochronology of the Swift Current granite and host volcanic rocks of the Love Cove Group, southwestern Avalon Zone, Newfoundland: evidence of a late Proterozoic volcanic–subvolcanic association. Canadian Journal of Earth Sciences, Volume 18, pages 699-707.

Hayes, A.O.
1948: Geology of the area between Bonavista and Trinity Bays, eastern Newfoundland. Geological Survey of Newfoundland. Bulletin 32, Part 1, pages 1-37.

Huard, A. and O'Driscoll, C.F.
1986: Epithermal gold mineralization in late Precambrian volcanic rocks on the Burin Peninsula. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 65-78.

Jenness, S.E.
1963: Terra Nova and Bonavista map areas, Newfoundland. Geological Survey of Canada, Memoir 327, 184 pages.

Keen, C.E., Keen, M.J., Nichols, B., Reid, I., Stockmal, G.S., Colman-Sadd, S.P., O'Brien, S.J., Miller, H., Quinlan, G., Williams, H. and Wright, J.
1986: A deep seismic reflection profile across the northern Appalachians. Geology, Volume 14, pages 141-145.

Knight, I. and O'Brien, S.J.
This volume: Stratigraphic and sedimentological studies of the Connecting Point Group, portions of the Eastport (2C/12) and St. Brendan's (2C/13) map areas, Bonavista Bay, Newfoundland.

Murray, A. and Howley, J.P.
1881: Geological Summary of Newfoundland (Reports for 1864 through 1880). Edward Stanford, London, 536 pages.

O'Brien, S.J.
1987: Geology of the Eastport (west half) map area, Bonavista Bay, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 257-270.

O'Brien, S.J. and Blackwood, R.F.
1987: St. Brendan's (2C/13), Newfoundland. Newfoundland Department of Mines, Mineral Development Division, Map 87-55.

O'Brien, S.J., Strong, P.G. and Evans, J.
1977: The geology of the Grand Bank (1M/4) and Lamaline (1L/13) map areas, Burin Peninsula, Newfoundland. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-1, pages 35-42.

Widmer, K.
1949: Unpublished map and incomplete report on the Glovertown–Clode Sound area. Geological Survey of Newfoundland. [2D9/65]

Williams, H.
1976: Tectonostratigraphic subdivision of the Appalachian orogen. *In* Abstracts with Programs, Volume 8, Number 2. Geological Society of America, Northeast Section Annual Meeting, page 200.

Williams, H. and Hatcher, R.D. Jr.
1983: Appalachian suspect terranes. *In* Contributions to the tectonics and geophysics of mountain chains. *Edited by* R.D. Hatcher, Jr., H. Williams and I. Zeitz. Geological Society of America, Memoir 158, pages 33-53.

Younce, G.B.
1970: Structural geology and stratigraphy of the Bonavista Bay region, Newfoundland. Unpublished Ph.D. thesis, Cornell University, Ithaca, New York, 188 pages.

Note: Mineral Development Division file numbers are included in square brackets.

*Current Research (1988) Newfoundland Department of Mines
Mineral Development Division, Report 88-1, pages 207-228*

STRATIGRAPHY AND SEDIMENTOLOGY OF THE CONNECTING POINT GROUP AND RELATED ROCKS, BONAVISTA BAY, NEWFOUNDLAND: AN EXAMPLE OF A LATE PRECAMBRIAN AVALONIAN BASIN

Ian Knight and Sean J. O'Brien
Newfoundland Mapping Section

ABSTRACT

The Connecting Point Group in the Bonavista Bay area is composed of a thick pile of uppermost Precambrian epiclastic, marine turbiditic sandstone, siltstone, shale and silicified sediment. The succession lies conformably above the mainly volcanic Love Cove Group and unconformably beneath the volcanic and siliciclastic Musgravetown Group. Black shale and interbedded pyroclastic rocks of the upper part of the Love Cove Group underlie the turbidites, but are also intercalated in the lower 500 m of the Connecting Point Group. To date, a total of six lithostratigraphic units and ten distinctive lithofacies, which comprise a 3.5-km-thick sedimentary pile, have been recognized within the Connecting Point Group in the study area. Sediments in this succession include lithofacies deposited in basinal and slope settings, prograding fan lobes and channel–levee complexes of submarine fans.

Predominance of T_a turbidites and poor development of coarsening- and fining-upward sequences in the lower 800 m of the group suggest that the sediments were deposited on a low-efficiency submarine fan as part of a thick volcaniclastic apron that lay adjacent to a volcanic centre. The well-developed channel–levee complex that comprises the next 1000 m of the succession suggests a change to a more efficient fan with time. Both lateral shifting and avulsion of channels occurred.

A thick shale transition containing thin siltstones and cherts, small- to large-scale slumps, and a regionally significant mixtite deposit comprising a mixture of sedimentary olistoliths and volcanic clasts, overlie the lower sequence. An upper sequence, above the mixtite, of silicified, classical turbidites are arranged in stacks of coarsening- and thickening-upward sequences, suggesting the existence of a series of well-developed, overlapping, prograding submarine fan lobes. The separation of the rocks into two distinct sequences is coincident with: 1) the introduction of mixtite into the basin, 2) the intrusion of mafic dykes and plutons, and 3) the influx of coarse volcanic detritus indicative of uplift of a volcanic source; these events suggest an episode of basin growth.

The lithostratigraphy and characteristics of the upper part of the Love Cove Group and the overlying Connecting Point Group resemble Cenozoic models of sedimentation in volcanic-arc basins. The linear Precambrian volcanic and sedimentary belts in the Avalon Zone may reflect an ancient arc–basin geometry affected only slightly by subsequent deformation.

INTRODUCTION

This report presents the preliminary results of detailed stratigraphic and sedimentological studies of the Connecting Point Group (Hayes, 1948) recently undertaken by the authors. In 1986 and 1987, our work focused mainly on the lower portion of the group, which is best exposed on the numerous islands west and northwest of the community of Burnside in southwest Bonavista Bay. Detailed sections were logged through the group in two southwest–northeast transects along the shores of 1) Long Reach and Pretty islands and 2) Hail and Coal islands. The study area was expanded in 1987 to include higher stratigraphic levels of the group exposed in the vicinity of Salvage and Eastport.

The aims of this study are four-fold. Through detailed sedimentological and stratigraphic analyses, coupled with regional systematic mapping, we hope to:

1) establish a regional stratigraphy for the Connecting Point Group,
2) establish the group's paleogeographic setting,
3) compare and contrast the evolution of late Precambrian basins in southeastern Newfoundland, and in doing so,
4) use depositional history of these basins to provide insight into the tectonic setting of the Avalon Zone.

The Connecting Point Group is an extensive succession of late Precambrian, marine, siliciclastic sedimentary rocks that forms a southward-narrowing belt underlying more than 3000 km² between Offer Gooseberry Island in Bonavista Bay and Long Island in Placentia Bay (Figure 1). The group occupies a stratigraphic position conformably above the mainly volcanic Love Cove Group and unconformably beneath the late Precambrian to ?Early Cambrian sedimentary and volcanic Musgravetown Group.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

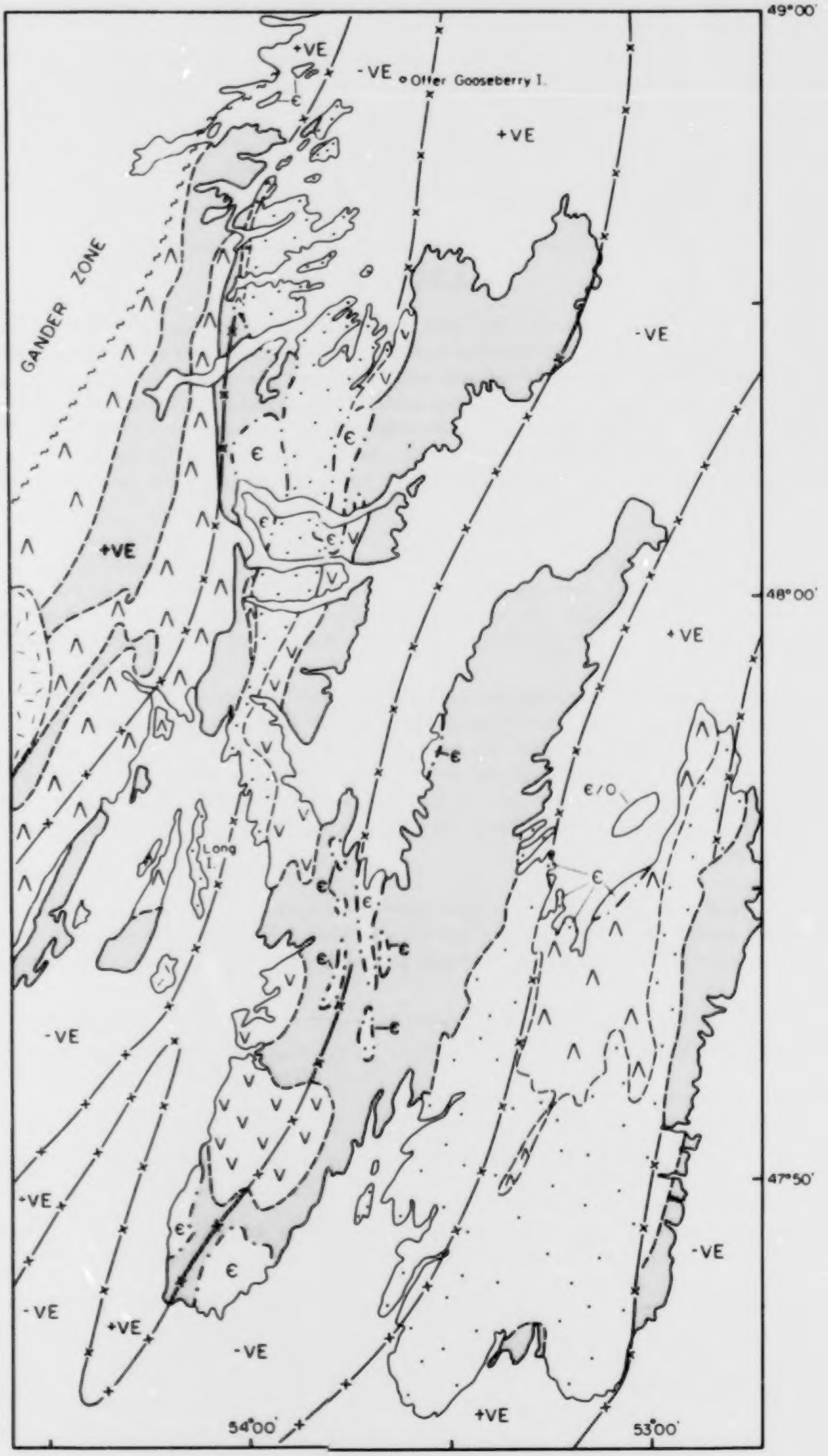

49°00'
+VE
-VE
Otter Gooseberry I.
+VE
GANDER ZONE
-VE
+VE
48°00'
+VE
Long I.
Є/O
-VE
+VE
47°50'
-VE
-VE
+VE
-VE
+VE
54°00'
53°00'

Figure 1. *Regional distribution of volcanic and sedimentary rocks of the Avalon Zone. The aeromagnetic belts of Haworth and Lefort (1979) are also shown (see legend).*

LEGEND (Figure 1)

⁄ ˋ ⁄	*Intrusive rocks*
☐	*Cambrian – Ordovician sedimentary rocks*
V	*Late Hadrynian sedimentary and volcanic rocks; includes Musgravetown Group*
⋯	Connecting Point Group – Conception Group: *mainly sedimentary rocks*
Λ	Love Cove Group – Harbour Main Group: *mainly volcanic rocks*

KEY

—·—·— *Unconformity*

—×— *Boundary of magnetic belts of Haworth and Lefort (1979)*
+ve positive magnetic belt
−ve negative magnetic belt

∼∼∼∼ *Fault*

The Connecting Point Group in the map area (Figure 2) is a succession of epiclastic, turbiditic sandstone, siltstone and shale containing subordinate amounts of chert, tuff and mixtite. The group is at least 3500 m thick. A total of 2400 m of section has been studied, primarily in the lower part of the group. The upper 780 m of the underlying Love Cove Group contains black shale, fine- to coarse-grained vitric, crystal and lithic tuff and agglomerate, and minor interbeds of thin turbiditic sandstone and volcanic breccia.

The sections studied on the islands west of Burnside (Figure 2, Figure 3) are part of an eastward-facing succession on the vertical to inverted western limb of the Willis Reach syncline (O'Brien and Knight, *this volume).* High-strain effects, combined with secondary silicification and the thermal effects of widespread dyking, hamper the definition of sedimentary structures in these sections. The sections near Eastport (Figure 2, Figure 4) lie mainly within the gently to moderately dipping eastern limb of an anticline. Sedimentary rocks of the Connecting Point Group in this limb, extensively silicified in places, are not highly strained.

Sections were measured using a metre stick. Where covered intervals were encountered, their thickness was calculated using measured horizontal distances multiplied by the sine of the angle of dip. Grain size of sandstones was visually estimated.

STRATIGRAPHY

In the study area, the Connecting Point Group is divisible into six lithostratigraphic units (O'Brien, 1987; O'Brien and Knight, *this volume).* The first five of these units have been mapped extensively on the western limb of the Willis Reach syncline; the younger units (C-3 to C-6) were mapped east of the synclinal core, where the older units are missing (Figure 2).

The six lithostratigraphic units, with brief summaries of their characteristic lithology, are listed below, in order of decreasing age. The various lithofacies are discussed in detail below (see LITHOFACIES).

UNIT C-1

Thin-bedded, green-grey and buff, tuffaceous sandstone and siltstone, black shale and rare fine grained pyroclastic rocks, and coarse grained epiclastic breccia. Although this unit is predominated by thin-bedded, tuffaceous siltstone and sandstone (lithofacies F and D), thicker massive sandstone (lithofacies G-1) is intercalated sporadically. Minor lithofacies in this unit are facies A-1, B and H. Sequences that show bed thickness and grain-size trends are not obvious. The unit is approximately 400 m thick.

UNIT C-2

Thick- to thin-bedded, commonly amalgamated, graded sandstone containing interbeds of thin-bedded green-grey sandstone and shale. This unit, predominated by lithofacies F and G, contains variably developed thickening- and coarsening-upward sequences involving shale (lithofacies A-1), thin- to thick-bedded, graded sandstone (lithofacies F and G-1) and rare pebbly sandstone (lithofacies G-1). The unit is pproximately 370 m thick.

UNIT C-3

Green-grey to buff, thinly bedded, very fine grained sandstone, siltstone and shale enclosing large lenticular units

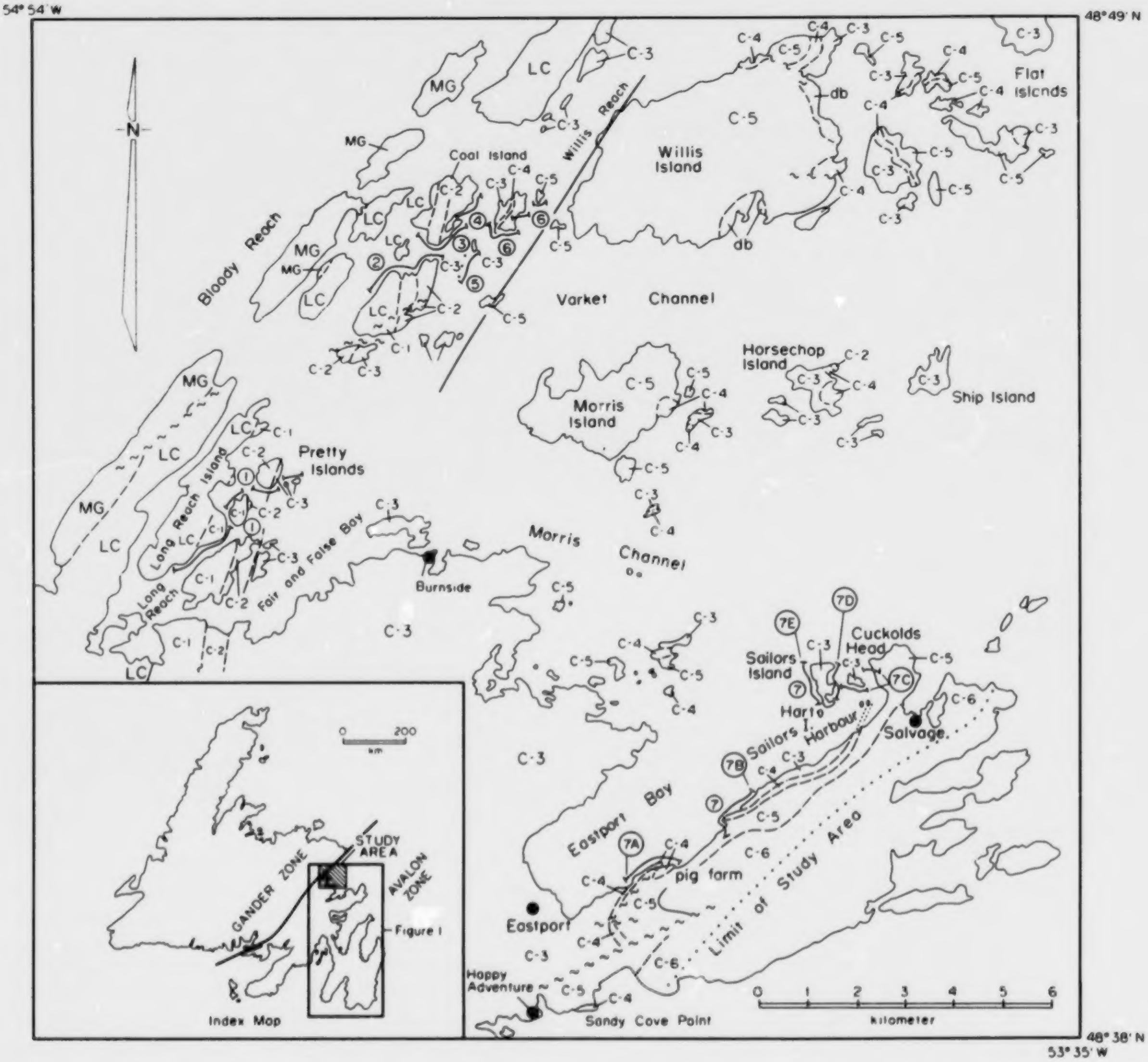

54° 54' W
48° 49' N
48° 38' N
53° 35' W
N
MG
LC
Coal Island
Willis Reach
Willis Island
Bloody Reach
Varket Channel
Horsechop Island
Ship Island
Flat islands
Morris Island
Pretty Islands
Long Reach Island
Long Reach
Fair and False Bay
Burnside
Morris Channel
Cuckolds Head
Sailors Island
Harts Harbour
Salvage
Sailors I.
Eastport Bay
pig farm
Limit of Study Area
Eastport
Happy Adventure
Sandy Cove Point
db
C-1
C-2
C-3
C-4
C-5
C-6
①
②
③
④
⑤
⑥
⑦
7A
7B
7C
7D
7E
0 1 2 3 4 5 6
kilometer
0 200
km
STUDY AREA
GANDER ZONE
AVALON ZONE
Figure 1
Index Map

Figure 2. *Geologic map showing lithostratigraphy of the Connecting Point Group in the Eastport–Salvage area of Bonavista Bay. Numbered sections illustrated in Figures 3 and 4 are also shown.*

of massive and pebbly sandstone (lithofacies E and G). Black shale (lithofacies A-1 and A-2) is locally intercalated in the unit. A minimum of 1000 m of this unit is exposed in the study area.

UNIT C-4

Mixtite. This unit varies from 11 m to 17 m in thickness, and is a widely distributed marker in the map area. It contains sedimentary, volcanic and minor plutonic clasts that are set in a muddy matrix. Locally, the mixtite (lithofacies I) appears to pass laterally into shale and thin-bedded siltstone and sandstone (lithofacies A-3) deformed by medium- to large-scale slump folds.

UNIT C-5

Shale containing thin-bedded sandstone and siltstone, colour-banded shale and siltstone, thick sandstone, slump beds and chert. Small- to large-scale slump folds, slump breccia, slides and slump scars are present within shale and siltstone (lithofacies A-3) of the unit, especially in the Eastport–Salvage area. Colour-banded shale and siltstone (lithofacies C), unaffected by synsedimentary deformation, forms an important part of this unit in the vicinity of Willis Reach. Distinctive, thick units of sandstone (lithofacies G and H) overlie the mixtite on Willis and Morris islands in the northeastern part of the area. These units display well-developed, internal, planar, thin stratification (see Plate 4 of

LEGEND (Figure 2)

UPPER PRECAMBRIAN

MG	*Undivided Musgravetown Group*
	Connecting Point Group (Units C-1 to C-6)
C-6	*Black shale, thin-bedded argillite, silicified thin- to medium-bedded turbidite sandstone.*
C-5	*Shale, thin-bedded sandstone and siltstone, and thick units of sandstone; planar stratified and slumped sandstone.*
C-4	*Mixtite containing pebble- and boulder-sized clasts of sedimentary rocks together with mafic and felsic volcanic and plutonic detritus.*
C-3	*Green-grey to buff, thin-bedded sandstone, siltstone and shale containing units of massive pebbly sandstone and black shale.*
C-2	*Thick-bedded, thin-bedded and amalgamated turbidite sandstone containing minor thin-bedded, green-grey sandstone and shale.*
C-1	*Thin-bedded green-grey and buff tuffaceous sandstone and siltstone; black shale; rare pyroclastic rocks.*
LC	*Undivided Love Cove Group*

SYMBOLS

~~~ *Fault*

--- *Stratigraphic contact*

⑤ *Location and number of logged section*

O'Brien and Knight, *this volume)* that is, in many places, convoluted. In general, thin sandstone and siltstone units are unsystematically distributed throughout the shales. However, some coarsening- and thickening-upward sequences involving shale (lithofacies A-2) and sandstone (lithofacies F-2 and F-1) occur near the top of the unit. The unit is at least 500 m thick.

UNIT C-6

Thin- to thick-bedded sandstone and shale. These sandstones display characteristic features of turbidites (lithofacies F and locally G-1), and are arranged in well-developed, coarsening- and thickening-upward sequences with thicknesses as great as 70 m. The top of the unit has not been mapped but the minimum thickness is 900 m.

The Connecting Point Group conformably overlies the Love Cove Group. On Hail Island, the conformable contact is placed where a continuous succession of well-bedded, fine grained, epiclastic sedimentary rocks rest upon coarse pyroclastic rocks and interbedded shales of the Love Cove Group (St. Brendan's map area (2C/13), grid reference 2946, 540535). The two groups are compositionally similiar, and contain common lithofacies (see Table 1). Shales and pyroclastic rocks predominate near the top of the Love Cove Group and form minor units in the basal unit of the Connecting Point Group. Similarly, units of thin-bedded shale and tuffaceous sandstone are in many places interdigitated with volcanic rocks in the upper unit of the Love Cove Group. These observations indicate that the contact between these groups is transitional.

LITHOFACIES

Ten lithofacies are recognized in the Connecting Point Group. Lithofacies A, B, D and F also occur in varying proportions in the underlying Love Cove Group. Lithofacies is here used in accordance with definition b in the Glossary of Geology (Bates and Jackson, 1987, page 383) as 'a term used by Moore (1949) to signify any particular kind of sedimentary rock or distinguishable rock record formed under common environmental conditions of deposition, without regard to age or geological setting or without reference to designated stratigraphic units, and represented by the sum total of the lithologic characteristics of the rock.'

Lithofacies A: Shale

Description. Shales found in the Connecting Point and Love Cove groups are divisible into three subfacies. The first (subfacies A-1) consists of thick sequences of generally monotonous black shale containing fine siliciclastic laminations, thin grey chert beds and minor fine grained schistose tuff. The shale is sulphurous, pyritic and commonly rusty. It is found mostly in Unit C-1 of the Connecting Point Group and in the Love Cove Group. Subfacies A-2 consists of black to grey shale that contains lenses and thin beds of laminated siltstone, and/or crosslaminated and laminated
~~~

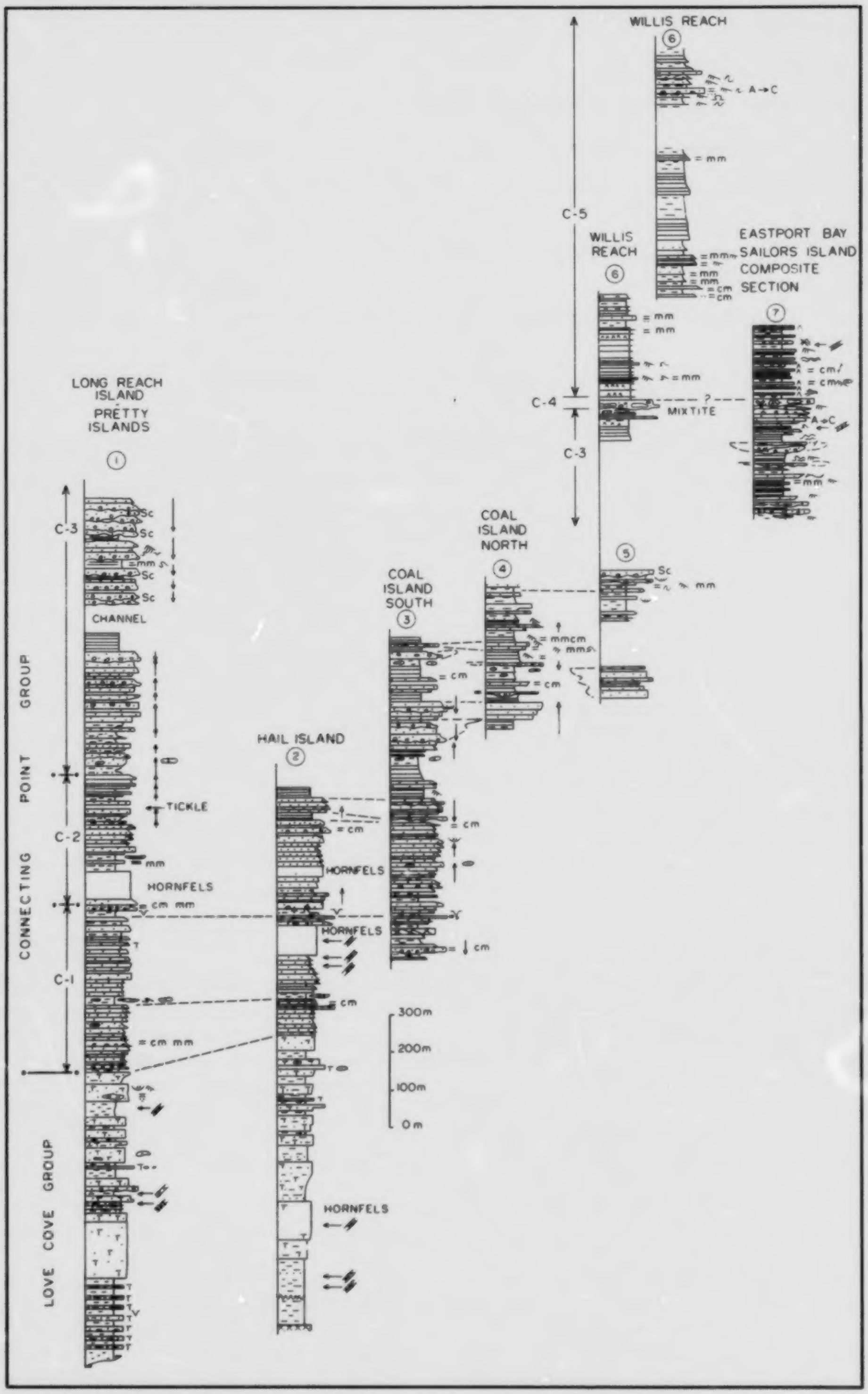
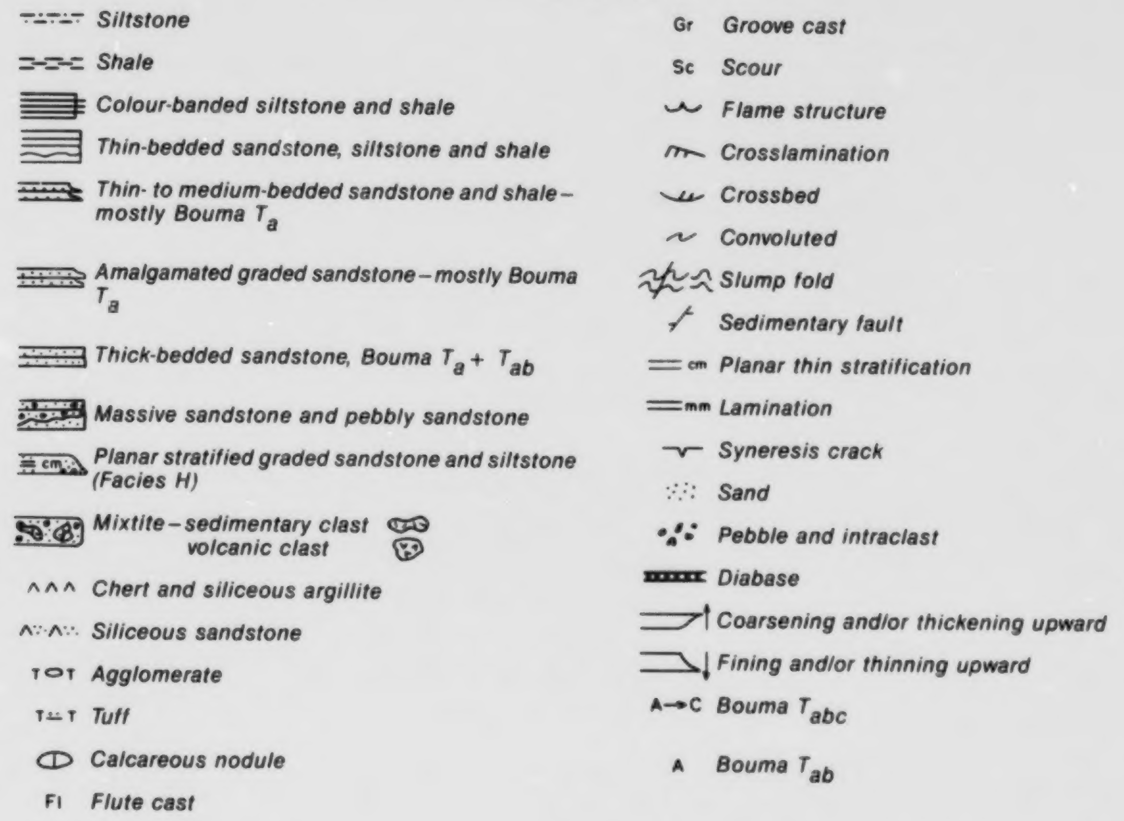

WILLIS REACH
⑥
A→C
= mm
C-5
WILLIS REACH
⑥
EASTPORT BAY SAILORS ISLAND COMPOSITE SECTION
⑦
= mm
= cm
= mm
= mm
= mm
C-4
MIXTITE
A→C
= cm
= mm
C-3
LONG REACH ISLAND PRETTY ISLANDS
①
C-3
Sc
= mm
CHANNEL
CONNECTING POINT GROUP
TICKLE
C-2
mm
HORNFELS
cm mm
C-1
= cm mm
LOVE COVE GROUP
HAIL ISLAND
②
= cm
HORNFELS
HORNFELS
cm
HORNFELS
COAL ISLAND SOUTH
③
= cm
= cm
cm
COAL ISLAND NORTH
④
= mmcm
mms
= cm
⑤
Sc
mm
300m
200m
100m
0m

Figure 3. *Graphic logs of sections through the Connecting Point Group, Bonavista Bay.*

KEY (Figure 3)


Siltstone
Shale
Colour-banded siltstone and shale
Thin-bedded sandstone, siltstone and shale
Thin- to medium-bedded sandstone and shale – mostly Bouma T_a
Amalgamated graded sandstone – mostly Bouma T_a
Thick-bedded sandstone, Bouma T_a + T_{ab}
Massive sandstone and pebbly sandstone
cm
Planar stratified graded sandstone and siltstone (Facies H)
Mixtite – sedimentary clast
volcanic clast
Chert and siliceous argillite
Siliceous sandstone
Agglomerate
Tuff
Calcareous nodule
Fl
Flute cast
Gr
Groove cast
Sc
Scour
Flame structure
Crosslamination
Crossbed
Convoluted
Slump fold
Sedimentary fault
cm
Planar thin stratification
mm
Lamination
Syneresis crack
Sand
Pebble and intraclast
Diabase
Coarsening and/or thickening upward
Fining and/or thinning upward
A→C
Bouma T_{abc}
A
Bouma T_{ab}

siltstone and very fine grained sandstone (Plate 1). It occurs mostly in Unit C-3 and C-5. The shale of subfacies A-2 forms the lower part of coarsening- and thickening-upward sequences involving bedded and parallel-bedded sandstone and massive and pebbly sandstone (lithofacies F and G). Subfacies A-3 consists of green-grey shale containing thin interbeds of parallel-laminated siltstone. The rocks have evidence of large-scale synsedimentary slump folding and brecciation, and are associated with slump scars and rotated bedding (Plate 2). They occur in Unit C-5 in close proximity to mixtite of Unit C-4.

Interpretation. Black, pyritiferous shales displaying lamination (subfacies A-1) suggest pelagic deposition in anoxic, basinal settings, away from active deep-water submarine fans or active volcanic centres. The shale of subfacies A-2, which is associated with crosslaminated siltstone and very fine grained sandstone, is deposited commonly within upward-thickening and upward-coarsening sequences and is characteristic of deposits of distal regions of submarine fans. The importance of slump features in subfacies A-3 suggests that the shale and thin siltstone represent deposition on the basin slope.

Lithofacies B: Pyroclastic Rocks and Tuffites

Description. Fine grained vitric tuff, fine- to coarse-grained lithic tuff, volcanic breccia and conglomerate are a significant, though minor, component of the basal part of the Connecting Point Group. Similar rock types are common in the upper Love Cove Group, where they are arranged in upward-coarsening sequences that begin with shale, pass upward into vitric tuff, and are completed by crystal and lithic tuff. Some sequences are capped by volcanic breccia. Shale (lithofacies A-1) predominates in the lower sequences, but forms equal proportions with tuff in the higher sequences in the Love Cove Group. In the Connecting Point Group, the lithofacies is intercalated with shales (subfacies A-1) or within turbidites of facies F; no textural sequences are obvious.

Generally the vitric tuffs are microcrystalline, green-grey and characteristically form planar, thin beds containing microflame structures and small-scale cracks preserved locally at the base. Internally, the beds are either structureless, graded, laminated or deformed. The deformed beds exhibit either a swirled texture defined by either microcrystalline or silty tuff, or a distinctive texture marked by blebs of the silty tuff set in a glassy matrix. Some siliceous, fine grained beds intercalated with the tuffs display locally convoluted crosslamination, load casts at the base and distinct normal grading accompanied by massive to laminated structure.

Lithic tuffs are composed of quartz, feldspar and fragments of tuff and shale. Some beds resembling fine grained, pebbly mudstone contain fragments suspended in

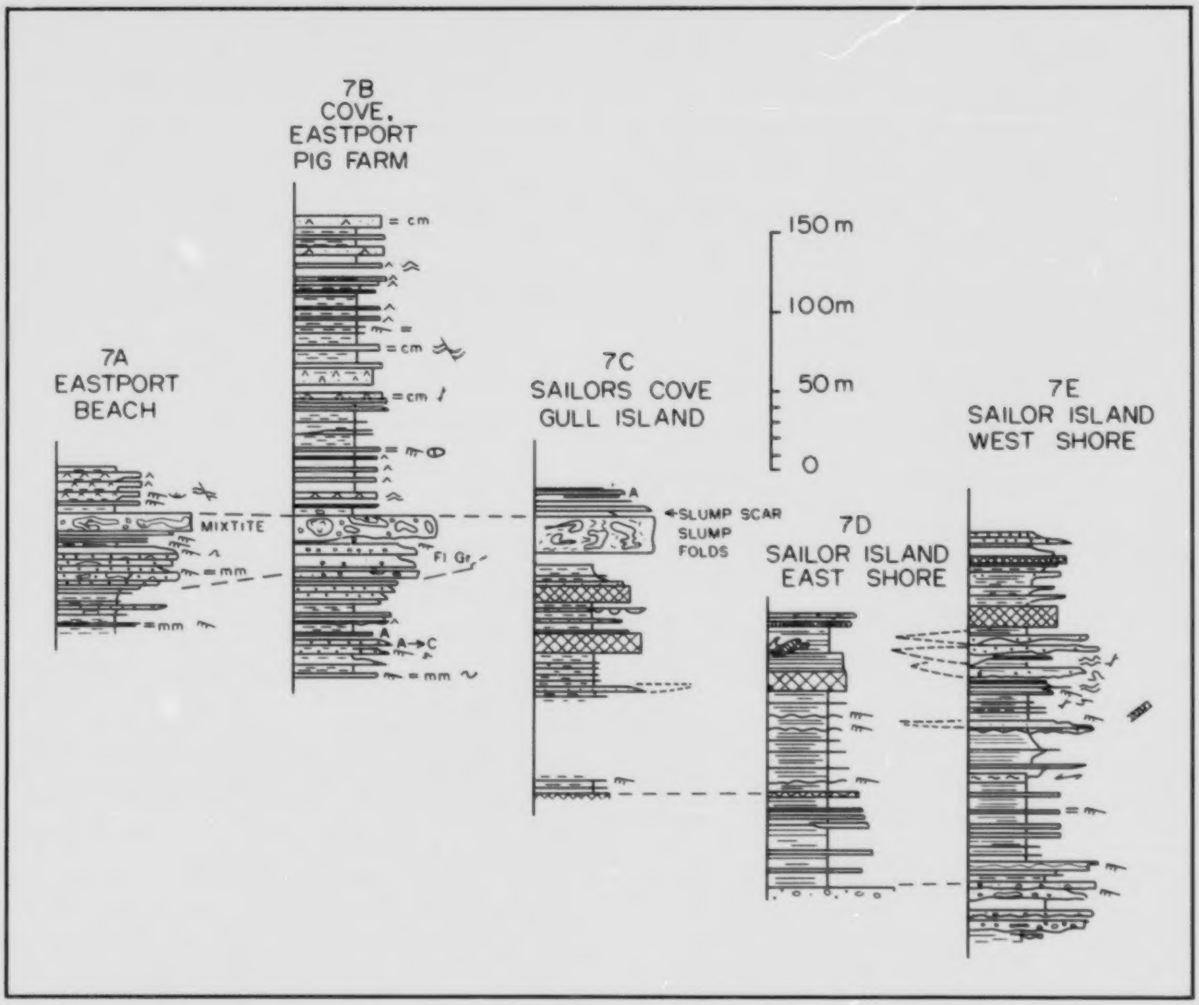


Figure 4. *Graphic logs of sections through units C-3 to C-5 in the Eastport Bay and Sailors Harbour area; see Figure 3 for key.*

an unsorted, finer grained matrix. Feldspars are either euhedral, flattened or bicuspate. Depositional fabrics are rarely preserved in the lithic tuffs, although inverse grading is locally developed.

Volcanic breccia and agglomerate occur in massive beds up to several metres thick. The beds have sharp bases and tops, unsorted grains, and normal and inverse grading; some beds change upward from massive to planar stratified. Locally, both rock types contain tuff and shale clasts up to 12 cm in diameter.

Interpretation. The intercalation of the tuffs and agglomerates with pelagic shales suggests that they are submarine pyroclastic rocks that accumulated in a basinal setting adjacent to one or several, explosive volcanic centres. The upward-coarsening nature of the sequences and the succession in the top of the Love Cove Group as a whole suggest that the basin fill accreted in response to repeated episodes of prolonged, increasingly violent volcanic eruptions. Many of the beds in the Love Cove and Connecting Point groups are characterized by structures indicative of density-current activity. The prevalence of internally deformed beds, beds of pebbly mudstone and graded beds with turbidite structure indicate abundant remobilization of the volcaniclastic sediments. Massive remobilization of sediment produced thick volcanic conglomerate and breccia. The suspended shale and tuff intraclasts in unsorted beds, and massive to stratified structure in graded beds suggest that these beds were subaqueous debris flows and turbidites.

Lithofacies C: Colour-banded Siltstone–Shale

Description. This facies consists of white-weathering, grey siltstone, green-grey silty shale and black shale that are intercalated in varying proportion through a 250-m-thick

Table 1. Sedimentary lithofacies of the Connecting Point and Love Cove groups, Bonavista Bay

Lithofacies	Characteristic Features	Environment
A: Shale	A-1: Grey to black; contains silicic laminae; pyrite, thin chert beds and fine grained tuffs	Quiet basinal
	A-2: Grey to black, contains lenticular and crosslaminated siltstones	Slope deposits; distal turbidites
	A-3: Green-grey with thin parallel laminated siltstone; abundant slump folds, breccias, scars and rotated bedding	Slope deposits
B: Pyroclastic sediments and tuffites	Fine grained, schistose, locally auriferous, vitric tuff, quartz-crystal tuff, lithic tuff and volcanic breccia and conglomerate; displays crude coarsening upward sequences	Associated with shale —quiet basinal setting, significant sediment gravity-flow deposits
C: Colour-banded siltstone—shale	Grey and green-grey, laminated and planar-bedded siltstone interbedded sharply with black shale	Slope sediments distal turbidites ?
D: Thin-bedded siliceous argillite, siltstone and shale	Planar, thin, laminated, crosslaminated and locally convoluted beds; fissure cracks; commonly thin units and intercalated with massive sandstone	Distal turbidites or locally abandoned fan-lobe channel
E: Thin-bedded very fine grained sandstone, siltstone and shale	E-1: Centimetre-scale, laminated or crosslaminated sandstone and siltstone, sharply interbedded with shale; some crosslaminated, 15-30 cm thick, very fine grained sandstone at base of fining-upward sequences up to 15 m thick; rare scours.	Distal levee
	E-2: Similar to E-1, but with common small-scale slump folds, faults, and convolutions; associated with tongues of massive sandstone and laterally with massive sandstone sequences	Near channel levee
F: Parallel-bedded sandstone—shale (in crude to well-developed coarsening upward and fining-upward sequences)	F-1: Metre-thick sequences of planar-bedded, thin- to medium-bedded, medium- to very fine-grained sandstone; generally structureless, but with some parallel lamination; sharp or gradational top with shale.	Mid fans and fan-lobe turbidites
	F-2: Crosslaminated and convoluted, very fine grained sandstone and shale	Outer fan turbidites
G: Thick-bedded, massive sandstone and pebbly sandstone; rare conglomerate	G-1: Thick-bedded, structureless sandstone; some amalgamated beds; contains intraclasts; graded from very coarse to fine grained.	Proximal turbidites and fan lobe channels
	G-2: Amalgamated, scoured, metre-thick beds of very coarse grained to granular sandstone; massive to planar-stratified, rarely crossbedded, crosslaminated, and convoluted.	Inner fan channels
H: Graded planar-stratified sandstone, siltstone and shale	Very thick; stratification throughout or may possess a thin basal massive interval; fining upward with intraclasts at base; locally convoluted and commonly interbedded with shale; locally occupy channels.	Crevasse splay, bypass fan lobe, deposited by mass emplacement
I: Mixtite	Pebble- to boulder-sized sedimentary lithoclasts (especially of facies D to F) plus rare to locally abundant mafic to felsic volcanic and plutonic detritus; folded blocks; chaotic to oriented fabric; matrix of granular to sandy mudstone; locally associated with facies G-2, and slump-folded sediments above; areally extensive in east area.	Olistostrome Inner channel deposit
J: Bedded chert and siliceous argillite	White to grey and black, stratified; units are thick, and locally preserve original sedimentary structure; slump folds are common.	Diagenetic for most part

Note: Lithofacies A-1, B, D and F are found in both Love Cove and Connecting Point groups. All other lithofacies occur within the Connecting Point Group.

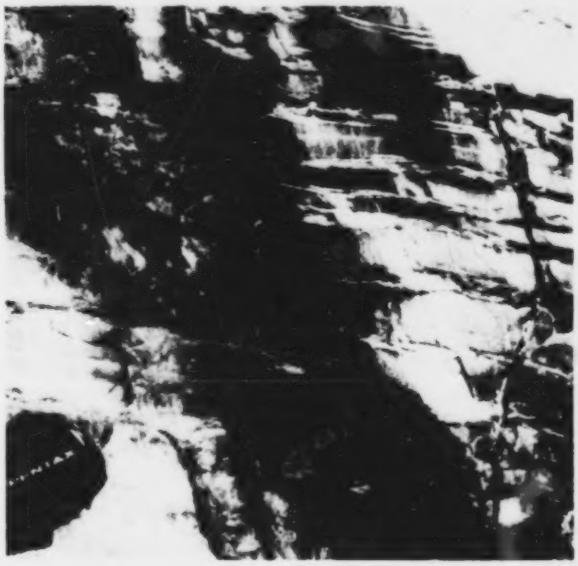


Plate 1. *Black shale of subfacies A-2 containing thin, crosslaminated, very fine grained sandstone (Unit C-4), Eastport Bay.*

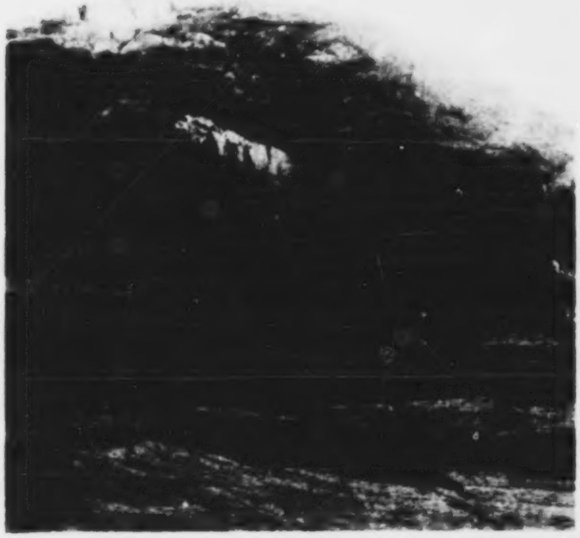


Plate 2. *Thin-bedded, green-grey shale and siltstone of subfacies A-3 overlain by a thickly slumped unit involving shale and bedded chert. Note the slump scar (arrow) truncating upturned bedding in the shales. Cuckolds Point, Sailors Harbour; scale is 1 m long.*

Plate 3. *Colour-banded siltstone and shale lithofacies with major sandstone component; island in Willis Reach.*

section on an island in Willis Reach. The facies is characterized by green-grey silty shale and black shale couplets, a few centimetres thick, which are intercalated with thin beds and laminae of white-weathering, grey, laminated siltstone to fine grained sandstone (Plate 3). Each of the three rock types may predominate in intervals up to 70 cm thickness within the sequence. The lithofacies occurs in Unit C-5.

Interpretation. The thin-bedded shale couplets are interpreted to be pelagic and hemipelagic deposits that were deposited on a slope, and sheltered or distal areas of the basin. The lack of slump features in this facies does not preclude a slope setting, since stable slopes are documented in recent reviews of continental slope and rise sediments (Cook *et al.*, 1982). The thin, sharply interbedded siltstones and sandstones are thin deposits of bottom currents.

Lithofacies D: Thin-bedded Siliceous Argillite, Siltstone and Shale

Description. This facies has a limited distribution relative to others in the group and occurs as less than 1-m-thick units within thick sandstone intervals (lithofacies F and G) in Units C-1 and C-2. The argillite–siltstone is thin-bedded, laminated and crosslaminated and contains convoluted structures in many places. Thin beds and partings of shale separate the siltstone beds.

Interpretation. The fine grained, thin-bedded rocks of this facies are interpreted as thin turbidites that were deposited on temporarily abandoned fan lobes and lobe channels (also see lithofacies F).

Lithofacies E: Thin-bedded, Very Fine Grained Sandstone, Siltstone and Shale

Description. Rocks of this lithofacies form units up to 100 m thick, characterized by planar and laterally persistent, centimetre-scale beds, arranged in 3-m- to 18-m-thick, fining-upward sequences (Plate 4). They form a significant part of

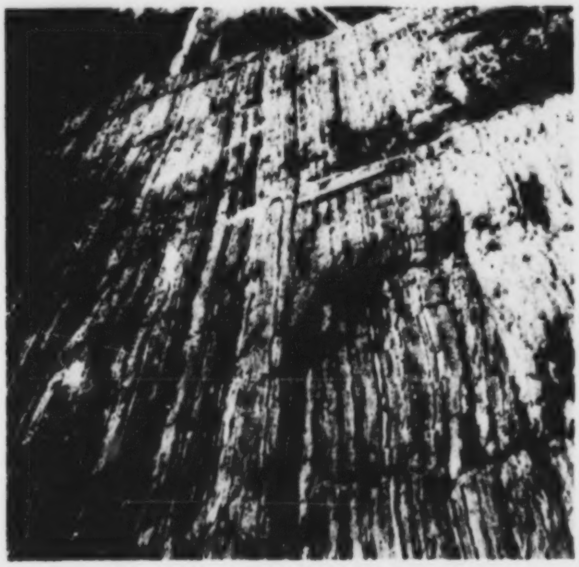


Plate 4. *Thin-bedded siltstone and shale of lithofacies E from the top of a fining-upward sequence on Coal Island; beds dip steeply to the left. Hammer is 33 cm long.*

Unit C-3, where they are intercalated with lenticular units of massive sandstone (see lithofacies G below).

Each sequence (subfacies E-1) begins with a fine- to very fine-grained sandstone bed that is rarely more than 60 cm thick. The sandstone is commonly crosslaminated and convoluted above a sharp to locally scoured base. Above the basal bed, the sequence continues with thin-bedded, crosslaminated, very fine grained sandstone and coarse siltstone containing shale partings. Upward in the sequence, shale interbeds thicken and occur in equal proportion to the coarser grained rocks (Plate 4); the top few metres of a sequence may consist entirely of black shale.

In the western limb of the Willis Reach syncline, discontinuity surfaces such as slump scars are apparently absent. Crosslaminated sandstone forms 10- to 20-cm-thick interbeds in the the lithofacies below intercalated units of massive sandstone (see lithofacies G, below).

On Sailors Island, near Salvage, 20-cm- to 40-cm-thick beds of structureless, very coarse- to fine-grained sandstone and intraclastic, sandy mudstone intertongue in the thin-bedded lithofacies (subfacies E-2) adjacent to the channel-bounding, lithofacies G sandstone (Plate 5). Individual sandstone tongues are, in most places, scour based and contain shale rip-ups. Massive beds of coarse grained sandstone are traceable along strike into crossbedded or crosslaminated, fine grained sandstone. The host thin-bedded facies consists of thin to locally 30-cm-thick, beds and lenses of coarse- to very fine-grained sandstone, interbedded unsystematically with shale units of equal thickness. The sandstone is consistently crosslaminated. The thin-bedded facies is also characterized by the presence of the following features:

Plate 5. *Channel scour (arrows) at base of massive sandstone (facies G) marking erosion into proximal sediments of facies E. Note the sandstone bed intercalated with the thin-bedded facies below the channel; western shore of Sailors Island.*

1) small slump folds (Plate 6) that have north-northeast- to east-northeast-trending axial planes that dip shallowly to steeply eastward,

2) local slump breccia,

3) small slump scars, and

4) small-scale synsedimentary faults.

The above association occurs on the western shore of Sailors Island. In contrast, 500 m eastward, on the eastern shore of the island, synsedimentary deformation is virtually absent. There, the succession (subfacies E-1) consists of rhythmically interbedded thin sandstone and shale (Plate 7), interrupted only rarely by single, thick, coarse grained sandstone beds. The thin sandstones are, for the most part, very fine grained, sharp based and sharp topped, and internally crosslaminated. Locally, the thin sandstones form graded beds that are either massive to laminated or laminated to crosslaminated with basal load casts.

Interpretation. The association of lithofacies E with units of channeled sandstone (lithofacies G) indicates that there is a genetic relationship between the two facies. The thin-bedded facies is interpreted to have been deposited as levees adjacent to channels. The proximal levee deposits are characterized

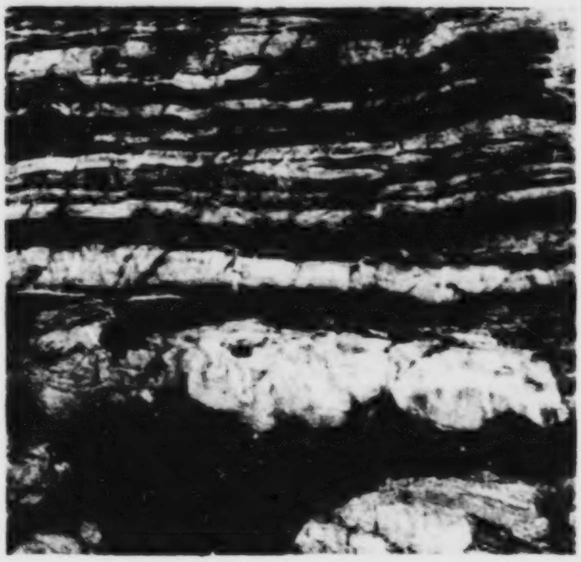


Plate 6. *Soft-sediment deformation in thin-bedded, laminated sandstone and shale of facies E; western shore of Sailors Island.*

Plate 7. *Rhythmic interbedding of shale and thin sandstone, distal levee sediments of lithofacies E; eastern shore of Sailors Island. Scale is 1 m long.*

by sandstone of variable grain size, abundant synsedimentary deformation, and crosslamination that is directed away from the channels. The distal levee deposits are rhythmically bedded and generally free of soft-sediment deformation as seen on the eastern shore of Sailors Island. The fining-upward sequences exposed on the western limb of the Willis Reach syncline are interpreted as the probable response of overbank sedimentation to lateral channel migration or gradually silting up of the channel with time.

Lithofacies F: Parallel-bedded Sandstone–Shale

Description. Lithofacies F is especially well developed in the lowest two stratigraphic units of the Connecting Point Group. It is characterized by laterally continuous, parallel-bedded, thin- to medium-bedded, medium- to very fine-grained sandstone (Plate 8). Thick-bedded sandstone occurs as either single beds or groups of beds. The sandstone beds have sharp, planar bases, and are internally structureless; they grade up into shale. Thicker sandstone beds are, in most places, massive; some display planar, thin stratification and lamination toward their top. A few beds display crosslamination at the top.

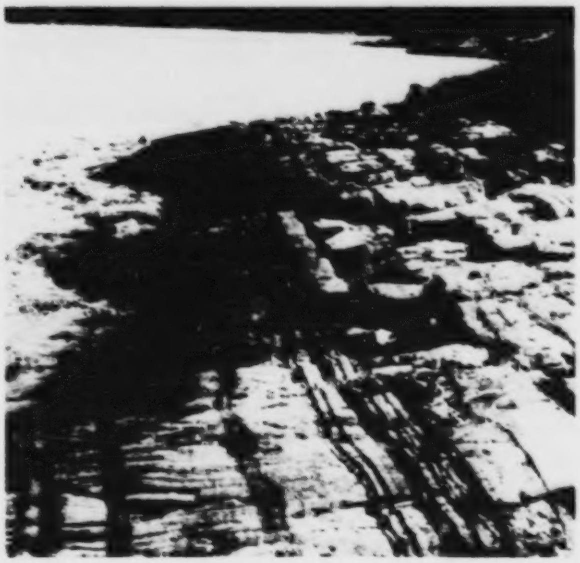


Plate 8. *Thin- and medium-bedded sandstone and shale of facies F, Hail Island; beds dip steeply to right.*

Thin-, medium- and thick-bedded sandstones are commonly amalgamated. Amalgamation (Plate 9) is recognized by the presence of coarser grained sandstone layers, which include euhedral and flattened feldspar grains, and also by the presence of either slivers of shale or bedding-parallel zones of elongate shale fragments, suspended in the sandstone bed. In some instances, zones of shale clasts can be traced into a shale interbed that separates sand beds. Calcareous concretions locally cement the sandstones.

This lithofacies also occurs in the shale-dominated lithostratigraphic units above and below the mixtite near Eastport and Salvage, where thickening- and coarsening-upward sequences are exposed. Individual thin sandstone beds are typified by laminated to crosslaminated divisions above planar bases. Medium-bedded sandstones include a massive division alone (top photograph, Plate 14), or there is an accompanying laminated and, rarely, crosslaminated division. Thick sandstone beds at the top of sequences have thick,

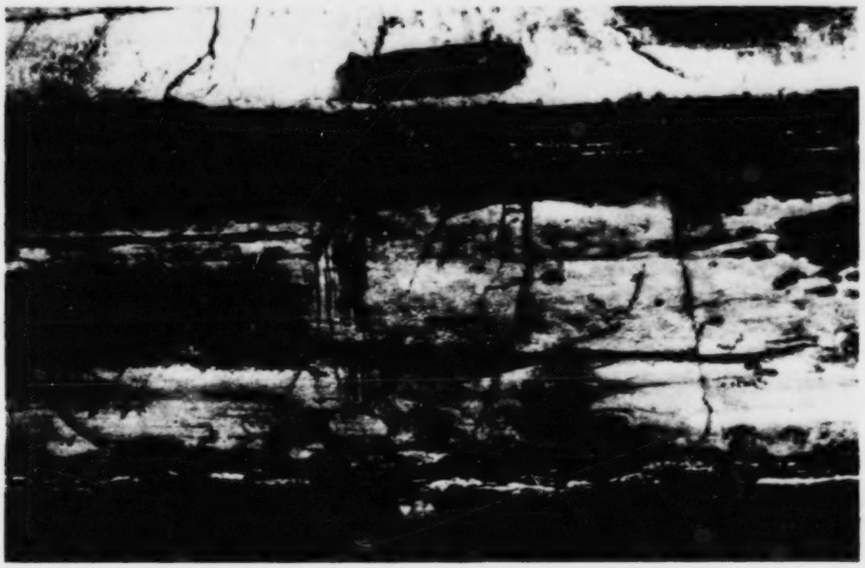


Plate 9. *Amalgamated beds of facies F, Coal Island. Note the flat shale intraclast and layer of coarse, light-weathering feldspar grains in the middle of the bed.*

massive divisions, overlain by laminated and convoluted crosslaminated divisions. Flute and groove casts occur on the planar bottoms of thick beds, which are locally deformed by loads. Small pebbles and shale rip-ups occur in the massive divisions of some thick beds.

Interpretation. The bedded sandstones of lithofacies F have all the characteristics of turbidites. The planar laminated and crosslaminated, thin sandstones exhibiting planar bases and good lateral continuity are distal turbidites deposited, for the most part, on the outer part of a submarine fan. Midfan and inner, fan-lobe settings are envisaged for the medium-bedded and thick-bedded sandstones that are characterized by sharp, planar bases, laterally continuous bedding, grading and massive division A of the Bouma sequence. The presence of well developed, upward-coarsening- and upward-thickening sequences is indicative of prograding fan lobes.

Lithofacies G: Thick-bedded, Massive Sandstone and Pebbly Sandstone

Description. The sandstones of this facies are distinguished by their very coarse- to fine-grain size and by their massive, thick-bedded, graded nature. The facies is a significant part of Unit C-3, but is also found in Unit C-2. Two distinctive sandstone subfacies are distinguished.

Sandstones of subfacies G-1 form 80-cm- to 1.5-m-thick beds that have good lateral continuity. They occur in units up to 95 m thick at the top of coarsening- and thickening-upward sequences involving turbidites of lithofacies F. Fine grained sandstone beds that occur at the base of these units give way to very coarse grained beds at the top of the units.

Each bed typically has a planar, sharp base overlain by graded, otherwise structureless sandstone, which in some thicker and coarser beds, is superseded by planar stratified sandstone. Shale intraclasts up to 10 cm in size occur in the massive division of the coarser grained sandstone beds.

Granular, intraclastic, pebbly sandstone forms subfacies G-2. These rocks commonly overlie subfacies G-1 sandstone where the latter first appears in the stratigraphic column. Subfacies G-2 units are 15 m to 95 m thick. Upward, the pebbly sandstone units are much thicker and are intercalated with fine grained, thin-bedded rocks of lithofacies E. Locally, erosional channels downcut several metres into the finer grained sediments. On Sailors Island, the scour has a step-like shape traceable into the channel (Plate 5). Within individual units, there are several major scour surfaces, each overlain by very coarse grained, pebbly sandstone that fines upward. Overall, the units also fine upward. Comparison of logs of adjacent sections suggests that the thickness of the sandstone beds varies from section to section and that some thin and pinch out.

The sandstone beds are between 1.5 m and 4 m thick. In general, the massive division of the bed (Plate 10) is overlain by graded, planar-stratified and locally convoluted sandstone that forms the upper half of the bed. In places, 25-cm-thick, trough cross-sets are present; locally, the uppermost part of the bed has convoluted crosslamination. Load casts and flames deform basal scours, and intraclasts, commonly imbricated, are concentrated close to the base of the bed. Locally, folded slabs of shale and thin-bedded sediment of lithofacies E, up to 1 m by 25 cm in dimension, are common in the scour-bound sandstones.

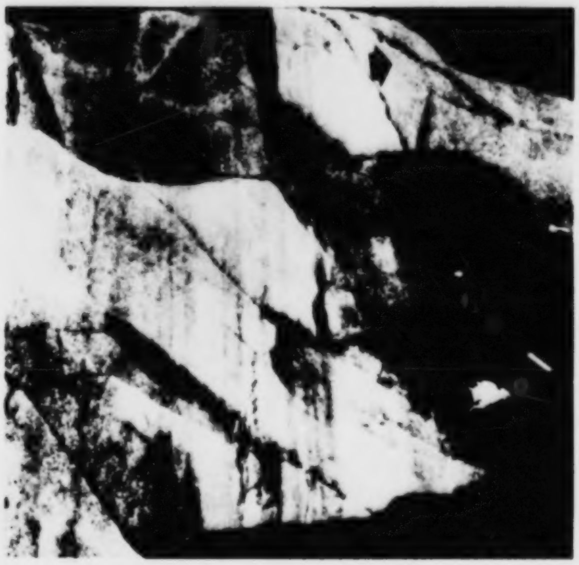


Plate 10. *Stratified and massive sandstone of facies G-2 separated by a scour (arrow), Pretty Island.*

Interpretation. The graded, massive, thick-bedded sandstones of subfacies G-2 display the characteristics of proximal, Bouma T_a and, less commonly, T_{a-b} turbidites, and are closely comparable to facies B_2 of Walker and Mutti (1973). The graded, massive nature suggests that they were deposited rapidly from suspension (Middleton and Hampton, 1976). This may also suggest that they were deposited from grainflows, although they lack inverse grading that is characteristic of these types of flows (Walker, 1984). These turbidites are characterized by: 1) sharp planar bases, 2) lateral continuity, and 3) upward coarsening within units. These features, coupled with the stratigraphic position of the turbidites above coarsening- and thickening-upward sequences, suggest that deposition occurred on the inner fan. The sharp bases and lack of channeling in the thick, massive sandstone indicate that it represents deposition on the fan lobe, either near distributary channel mouths or in a network of broad and shallow distributary channels.

The sandstones of subfacies G-2 fine upward and occur in lenticular, scour-bounded units, and are thus interpreted as channel deposits. The presence of the following features in these rocks indicate that they are channel deposits of deep-water submarine fans (Walker, 1978, 1984): 1) abundant scours, 2) coarse grained, graded sandstone, rich in intraclasts derived from erosion of associated levee sediments (lithofacies E), 3) locally channeled contacts with lithofacies E, and 4) massive to stratified, sedimentary structures associated with locally crossbedded and convoluted structures at the top of some beds. The lenticular distribution of these channel sand bodies suggests that they periodically switched their position on the fan by avulsion.

Lithofacies H: Graded, Planar-Stratified Sandstone, Siltstone and Shale

Description. This lithofacies most commonly occurs as single units, up to 14 m thick, intercalated within thin-bedded turbidites (lithofacies F) in the basal 500 m of the Connecting Point Group. Similar units occur within shales of lithofacies A and D in stratigraphic Units C-1, C-2 and C-5. One scour-based sandstone, 1.7 to 3.7 m thick, assigned to facies H fills a channel, 1.8 m deep and more than 30 m wide (Figure 5) in facies E rocks on Coal Island.

Where they are intercalated with turbidites of lithofacies F, the units are always graded. Individual beds have a scoured base overlain by an intraclastic, very coarse grained, tuffaceous sandstone that grades through very fine grained sandstone into siltstone. Locally, shale laminae occur at the top. Beds comprise a basal, 25-cm- to 50-cm-thick, shale-intraclastic structureless interval, overlain by a zone of cm-scale planar stratification (Plate 11), and capped by a laminated interval. The thick, stratified interval is composed of strata that display an upward decrease in thickness and grain size. Units are capped gradationally by a shale bed. Where they occur within shales in Units C-1, C-2 and C-5, the beds invariably begin with stratified, medium- to fine-grained sandstone and grade upward into siltstone. Locally, the stratification is disrupted by small-scale, soft-sediment folds and by convolutions.

Interpretation. The thick, graded deposits of this facies are interpreted as sediment gravity-flow deposits that occur anomalously in basinal settings (shale facies), on distal parts of deep-sea fan lobes (thin- to medium-bedded turbidites) and in small channels crossing overbank sediments of fan channels. They are distinguished by several features, including: 1) considerable thickness, 2) coarse grain size with shale rip-ups at the base, 3) upward fining, and 4) gradational change within a bed from structureless to stratified. These features indicate that the beds were deposited by thick, highly concentrated gravity flows, whose flow power waned gradually; they compare favourably with megaturbidites (Bouma, 1987). The occurrence of a massive basal interval with suspended shale rip-ups above a scoured base suggests that the sediment was carried into the distal settings by turbidity currents. Howell and Normark (1982) illustrate similiar thick units of very thinly stratified sandstone, which they attribute to mass emplacement. The great thickness of this lithofacies may reflect local ponding of the flows. The association of these rocks with basinal and distal fan lobe lithofacies and the channelized unit in the leveed sediments of lithofacies E suggests that they may be crevasse splay deposits.

Lithofacies I: Mixtite

Description. Mixtite is a nongenetic term (Schermerhorn, 1966) denoting a coarse grained, nonsorted or poorly sorted (mud- to boulder-sized detritus) clastic

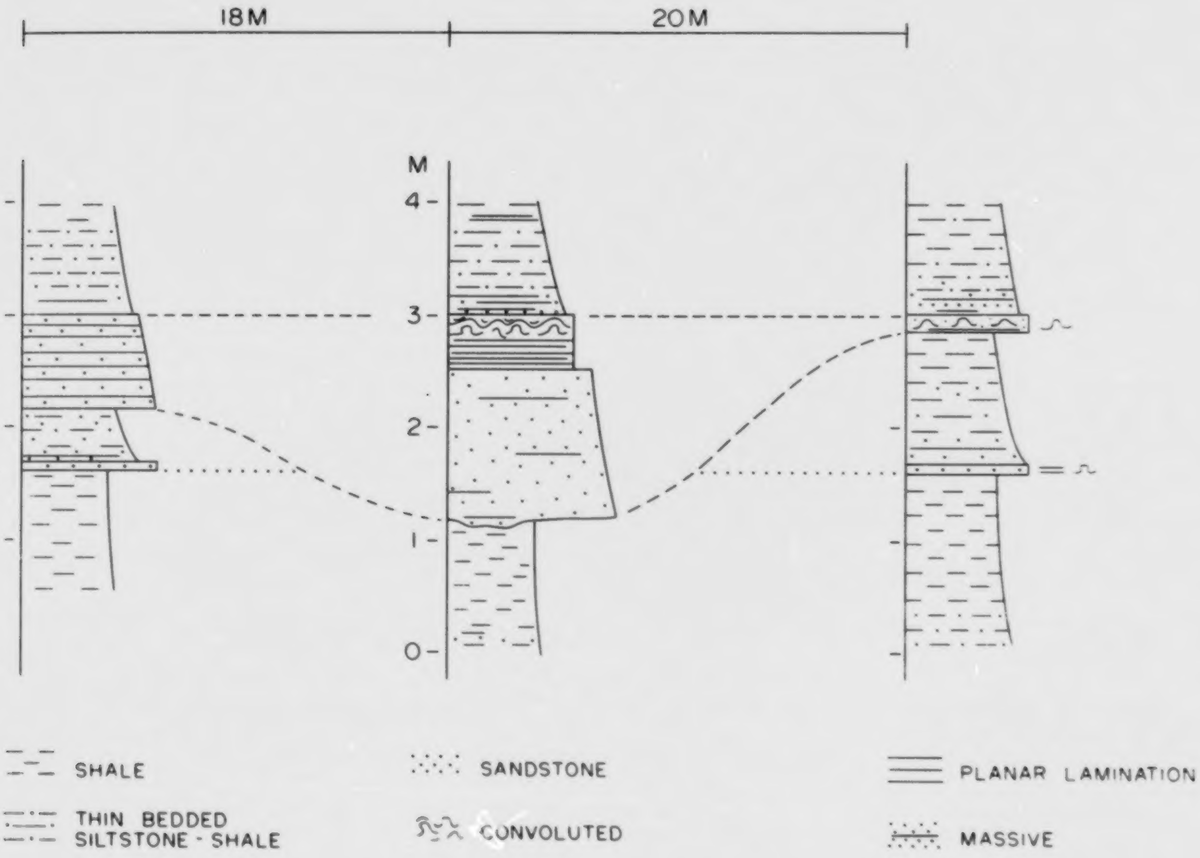


Figure 5. *Crevasse channel filled by laterally thinning, graded, massive to stratified sandstone in the north section (4) of Coal Island.*

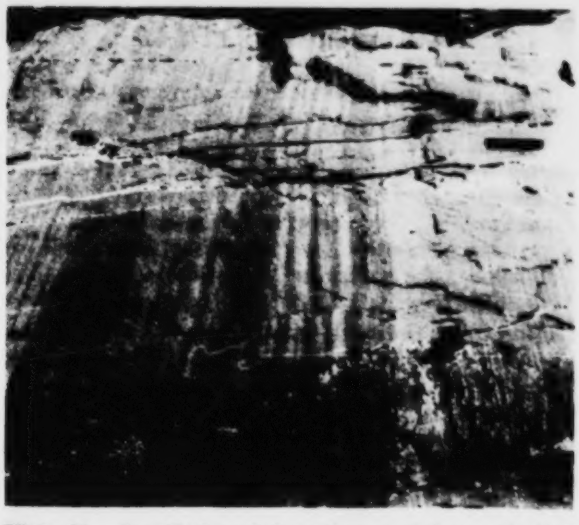


Plate 11. *Stratified-graded sandstone of facies H, Hail Island. Note the upward (to right) fining and thinning; scale is 10 cm long.*

sedimentary rock. It is used without regard to composition or origin of the rocks. This lithology forms a very widely developed, thin (11 to 17 m), lithostratigraphic unit (C-4) and lithofacies. The unit forms spectacular strike sections along the southeastern shore of Eastport Bay, and is well exposed near Happy Adventure and on the eastern shores of Willis and Morris islands. It also underlies Flat Islands and many adjacent smaller islands in this part of Bonavista Bay. On the western limb of the Willis Reach syncline, the mixtite is exposed only on one small island, located in Willis Reach. In the Eastport Bay section, the mixtite overlies a coarsening-upward sequence of shale, bedded turbidite and massive sandstone. On Horse Chop Island and Flat Islands, east of Morris Island, it rests abruptly upon variably silicified, thin-bedded turbidite and shale. On Flat Islands and at Cuckolds Head, near Salvage, the mixtite locally strikes laterally into sediments displaying large-scale slump folds and minor synsedimentary brecciation.

The mixtite consists of rafts of sedimentary olistoliths (Plate 12) supported in a brown-weathering, grey, mud- to sand-sized matrix (see Plate 3 of O'Brien and Knight, *this volume*). The sedimentary olistoliths are principally

Plate 12. *Mixtite containing deformed sedimentary olistoliths. Base of bed (arrow) is sharp; Eastport Bay.*

composed of shale, thinly interbedded shale and sandstone, bedded sandstone and shale of lithofacies F, and the thin-bedded, fine grained rocks of lithofacies E. Clasts of interbedded shale–chert and massive pebbly sandstone also occur. The olistoliths are invariably long slabs (up to 30 m and thickness up to 5 m) that are recumbently folded into S and Z shapes. In one section at Eastport Bay (grid reference 539395,30035, Eastport map sheet) clasts are chaotic. In another section, 1.5 km to the southwest (grid reference 539315,29955, Eastport map area), however, the clasts are oriented with their long axes trending southeast and their internal bedding dipping between 30 and 75 degrees southwest. Axes of folds in deformed slabs also trend southeast. In the Eastport Bay section, (grid reference 539395,30085, Eastport map area) the mixtite also includes scattered pebbles and blocks of felsic volcanic rocks and chert. The volcanic clasts are lithic tuff and agglomerate, quartz–feldspar porphyry, spherulitic rhyolite, vitric tuff and white and red silicic tuff. On Flat Islands, the mixtite contains more volcanic debris including pebbles of diabase. In general, the pebbles are up to 10 cm in diameter and subrounded. The largest volcanic block (Plate 13) occurs in the Eastport Bay section (grid reference 539395,30085, Eastport map area); it is approximately 13 m across.

The mixtite has a sharp, locally erosive, base. In some areas (e.g., Eastport Bay) the material comprising the mixtite bed ceased movement as it wedged up underlying sediment. In the same section, underlying bedding is buckled and locally thrust onto itself.

Interpretation. The mixtite is a massive, sediment gravity-flow deposit of regional significance derived largely by mobilization of sediments of the Connecting Point Group. This implies that it is a mass flow deposit caused by failure of unconsolidated sediment. That the mixtite can be traced laterally into slump-folded sediments locally associated with slump scars indicates that the mass flow deposit originated at the basin slope. At present, there is insufficent stratigraphic data to establish if there is more than one major mixtite sheet.

The proportion of incorporated felsic and mafic igneous detritus increases within the mixtite northeastward across the area. The occurrence of the 13-m block of lithic tuff and agglomerate in one section at Eastport Bay is anomalous to this general trend. Diabase pebbles are apparently localized in the area of Flat Islands. The diabase is believed to be derived from dykes that intruded wet sediments (O'Brien and Knight, *this volume)* and are common in the same area. This would mean that at least some of the plutonic detritus is locally derived. The felsic volcanic detritus, however, has a less localized source and may have been derived by erosion of the Love Cove Group or by resedimentation of mixtite that is perhaps equivalent to the lithologically similar Gaskiers Formation of the eastern Avalon Peninsula (Williams and King, 1979; King, *in preparation).* The anomalously large block described above may be a resedimented erratic transported from the shelf during slope failure.

Lithofacies J: Bedded Chert and Siliceous Argillite

Description. Thin, structureless, off-white and grey chert is interbedded with black shale near the base of the Connecting Point Group. In contrast, thick beds of brown-weathering, off-white to black chert and siliceous argillite are interbedded with shales and turbidites in the section above

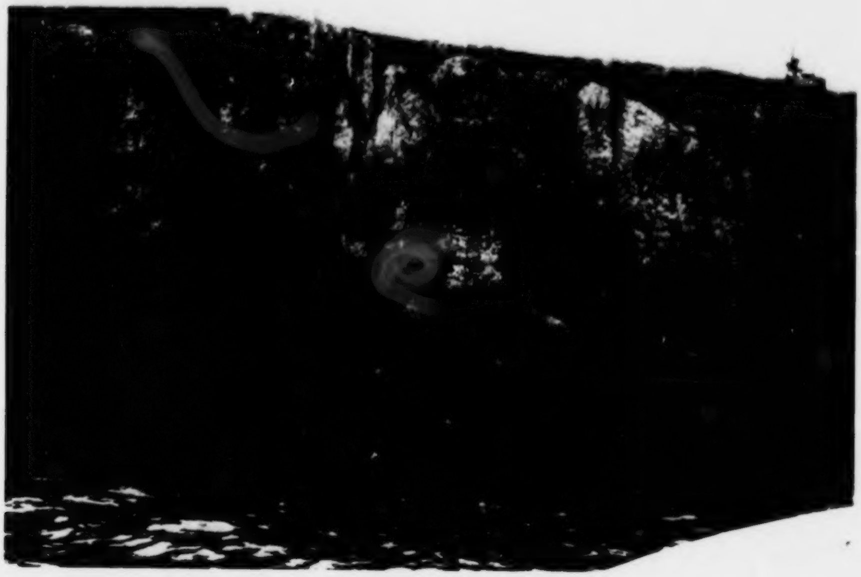


Plate 13. *Block (13 m across) of felsic tuff and agglomerate in the mixtite, Eastport Bay.*

and below the mixtite. The beds are up to 10.5 m thick and display the following sedimentary structures: 1) crosslamination, 2) planar lamination, 3) very thin stratification, 4) grading, 5) small-scale convolution, and 5) larger-scale synsedimentary buckling and thrusting.

Interpretation. The abundance and type of sedimentary structures within the chert and argillite indicate that these rocks are silicified sandstone and siltstone. The chert is interpreted as a diagenetic facies. The presence of chert pebbles of similar colour in some of the coarser grained, pebbly sandstone and mixtite, indicates that the chert formed just beneath or on the sea floor, soon after the original sediment was deposited. Similar cherts above the mixtite probably also formed at or just beneath the sea floor.

DISCUSSION

Basin Fill

The upper 800 m of the Love Cove Group and the overlying Connecting Point Group in the Eastport area record four stages in the evolution of a major late Precambrian depositional basin, here named the Eastport basin.

Stage 1. The first stage primarily involves the accretion of subaqueous, silicic, dominantly pyroclastic sediments (lithofacies B) in a basinal setting in which pelagic muds (subfacies A-1) accumulated. The presence of shale and lithic volcanogenic fragments in the coarser grained pyroclastic rocks, the occurrence of volcaniclastic debris flows, the intercalation of turbidites and tuffs containing internal deformation, all suggest abundant submarine reworking of the volcanic rocks in the basin. The silicification of volcaniclastic rocks of lithofacies B within the underlying Love Cove Group points to local hydrothermal activity at this time.

Stage 2. The deposition of 1600 to 1800 m of sandy turbidites derived from erosion of a volcanic edifice marks the second stage of basin fill. Although the sequence consists of sandstone that coarsens upward overall, it is divisible into at least two distinct parts; viz., a lower section 600 to 850 m thick, predominated by thin- to thick-bedded sandy turbidites, and an upper section (up to 1000 m thick) of channeled massive sandstone and pebbly sandstone associated with widely developed levee-facies- or overbank-facies shales and sandstones. The lower section probably preserves the deposits of lower fan and midfan (Walker, 1984); the upper section represents the levee-channel complex of the channeled inner fan (Walker, 1984, 1985).

The sequence deposited in stage 2 is interpreted to represent basinward progradation of the fan; the lower part of the Connecting Point Group (e.g., below mixtite) broadly fits the deep-water fan model of Walker (1978, 1984) and Normark (1978). The succession of these bedded turbidites, however, is not composed of classical turbidites arranged in well-developed upward-thickening and upward-coarsening progradation sequences of distal Bouma T_{bce} to proximal Bouma $T_{abe}-T_{ae}$ turbidites. Instead, it consists mostly of massive, graded, very fine- to medium-grained sandstone that was deposited rapidly by high-density flows.

The abundance of well-sorted sandstone and the poor development of Bouma sequences and of fining- and coarsening-upward sequences suggest that the deep-water fan was a low efficiency type (Howell and Normark, 1982; Walker, 1984). Howell and Normark (1982) report that abundant sand influx tends to produce shorter and less elevated leveed valleys on the inner fan. It also results in the association of units of medium- to thick-bedded, sandy turbidite bundles with thin-bedded turbidites or hemipelagic sediments, similar to those seen at the base of the Connecting Point Group. The poor sequence development in the sandy pile, however, may reflect interference of more than one source, especially in a relatively narrow basin. It is noteworthy that: 1) poorly developed deep-sea fans are common in volcaniclastic aprons that fill marginal basins of active volcanic arcs (cf. Sigurdsson *et al.*, 1980; Carey and Sigurdsson, 1984) and 2) sediment gravity-flow deposits may make up to 77 percent of these aprons (Sigurdsson *et al.*, 1980; Fisher and Schmincke, 1984).

The importance of levee deposits associated with lenticular channeled sandstone (Unit C-3) higher in the group suggests that the inner part of the fan hosted a well-developed, leveed-channel complex. This may indicate that the efficiency of the fan improved with time, so that there was greater differentiation of the sediment supplied to it.

Stage 3. The mixtite and overlying shale, together with colour-banded shale and siltstone characterized by locally abundant disturbed bedding, are diagnostic of the third stage in the basin fill. The shales are arranged, locally with thin- to medium-bedded turbidites, into coarsening-upward sequences near the top of this part of the succession. In general, however, sandstone is unsystematically distributed in the shale. The colour-banded shales and siltstones are interpreted to represent pelagic and hemipelagic slope deposits in which the terrigenous component is quite pronounced. The presence of mixtite and the laterally equivalent slump deposits near the base of this interval support a base-of-slope setting. Slumps of local origin and small downslope displacement of beds contrast with the mixtite, which is interpreted to be a mass-flow deposit that transported not only rafts of bedded sediments, but also volcanic and plutonic debris derived from elsewhere within or outside the basin.

Stage 4. The latest stage of basin development recorded in the map area involves the deposition of an upward-coarsening succession (approximately 1 km thick) of repeated upward-thickening and upward-coarsening sequences of thin-bedded distal to medium-bedded, more proximal, turbidites (Plate 14). The occurrence of these rocks indicate that this part of the succession is built of overlapping prograding fan lobes of the classical deep-sea fan model (Walker, 1984). The turbidites deposited in this stage show the structures associated with classical turbidites. It is premature to conclude, without the necessary petrographic support, that these differences reflect the development of a second generation of deep-sea fans that overlapped the earlier basin fill. Similar classical turbidites occur at the base of the Connecting Point Group section in the Placentia Bay area, where they underlie a deltaic sandstone—shale sequence and fluvial(?), pebbly sandstones and conglomerates (O'Driscoll and Muggridge, 1979). Mapping in the east half of the Eastport map area (O'Brien, 1987) indicates that the turbidites of stage 4 are very extensive in the higher stratigraphic portions of the group exposed in that region.

Correlation with the Conception Group

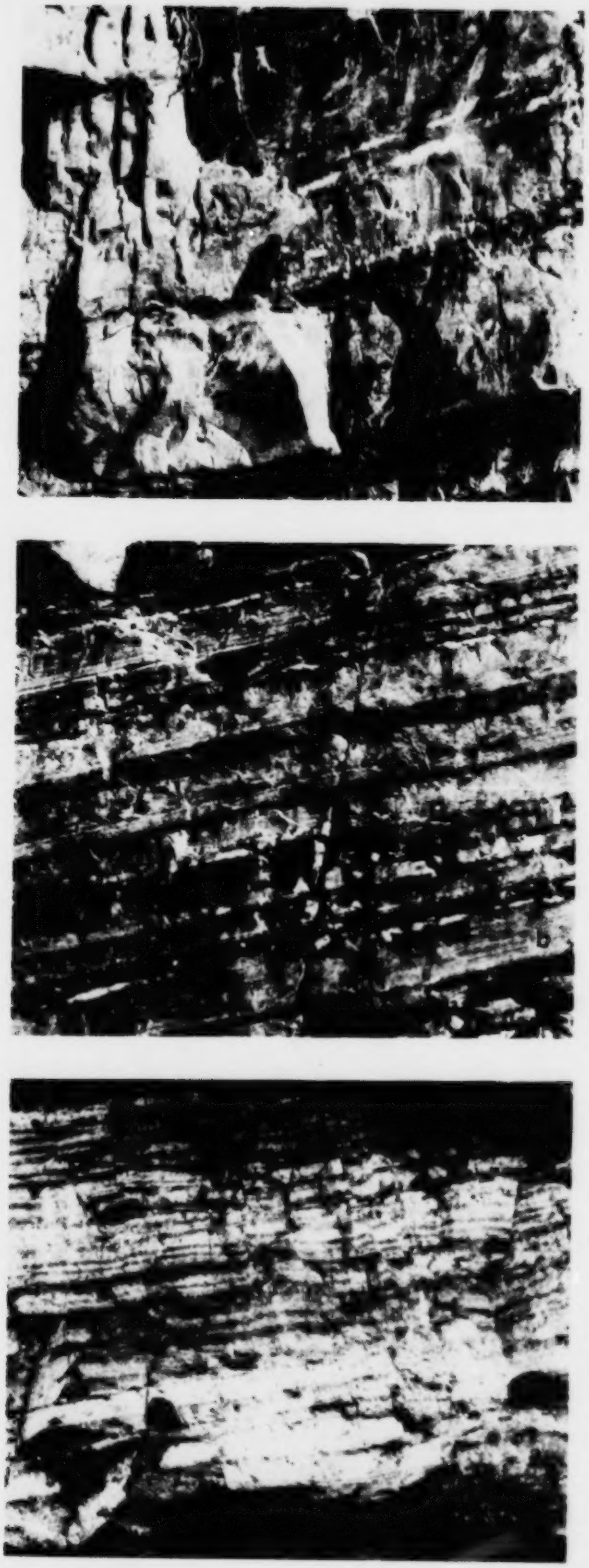
The Connecting Point Group is considered by many authors to be the chronostratigraphic and lithostratigraphic equivalent of the Conception Group (Rose, 1952) of the Avalon Peninsula (e.g., Buddington, 1919; Hayes, 1948; Jenness, 1963; McCartney, 1967). Although the two groups share a roughly common stratigraphic position above the main massifs of Avalonian volcanic rocks and below Avalonian molasse, it is not known if both successions were deposited in the same basin. However, certain broad similarities within the successions are apparent.

Significantly, both groups contain mixtites. In the Conception Group, evidence of a glacigenic origin for these rocks is recorded (e.g., Anderson and King, 1981). No such evidence has yet been recognized in the Connecting Point Group mixtite, but the remarkable lithological similarities of the mixtites, and their common occurrence beneath thick sequences of classical turbidites, supports crude regional correlation. The Mall Bay Formation (Williams and King, 1979) and the Broad Cove River Member of the Drook Formation (King, *in preparation)* of the Conception Group and the St. Phillips Formation of the Harbour Main Group (King, *in preparation)* may contain rocks stratigraphically equivalent to the premixtite portion of the Connecting Point Group. More data from both the Connecting Point and Conception groups is required before it is known if either: 1) both successions were deposited at roughly similar latitudes in the same basin and are now separated by faults and infolded younger sediments, or 2) each occupied a distinct basin.

Tectonic Setting

The Connecting Point Group underlies a southward-narrowing zone 150 km long, which has a maximum width of 30 km in the Eastport area. A succession of flysch, best exposed in the Eastport area and greater than 3.5 km thick, developed in this zone. The occurrence of these rocks, which occupy a stratigraphic position between the Love Cove and Musgravetown groups, suggests that a basin of large dimension evolved, filled and was deformed in a relatively short span of geological time (possibly as little as 30 Ma). The genetic and conformable relationship with the underlying Love Cove Group and the abundance of volcanic detritus in the sands of the group support a spatial relationship between the two groups possibly in a volcanic arc-basin setting. Volcanic rocks of the Love Cove Group in the Eastport area are of calc-alkali affinity (Hussey, 1979). The Connecting Point sediments of the Eastport basin are a volcaniclastic basin fill that were derived by erosion and reworking of flows, pyroclastics and epiclastic sediments of contemporaneous volcanic islands that surrounded the basin.

The alternating juxtapositioning of the volcanic and sedimentary belts within the Avalon Zone seen in the regional geological map of the zone (Figure 1) is highlighted by the regional aeromagnetic data of Haworth and LeFort (1979).



The offshore magnetic data indicate this pattern holds for the entire extent of the Avalon Zone north of the Collector Magnetic Anomaly (Haworth and LeFort, 1979), eastward to the continental margin. Although some structural modification of the original pattern has undoubtedly occurred, the absence of intense deformation affecting the terrane and the presence of regional unconformities between the Love Cove–Connecting Point groups and younger Precambrian and Lower Cambrian strata suggests that the pattern of alternating magnetic highs and lows, which corresponds on land to volcanic–plutonic and sedimentary successions, respectively, may in part, reflect the original late Precambrian configuration of linked volcanic ridges and sedimentary basins. The western limit of the Eastport basin, for instance, roughly marks the original western limit of an extensive marine basin that was situated east of a major volcanic terrane. Remnants of this volcanic terrane are preserved in the Love Cove Group and equivalents of the western Avalon Zone. In some modern geological settings, subparallel linear arcs and basins form where repeated arc spreading occurs through the history of an arc margin (Dickinsen, 1974; Carey and Sigurdsson, 1984). A modern example is the eastern margin of the Phillipine plate near the Mariana Trench (Hussong and Uyeda, 1981). The map of linear volcanic remnant and active arcs and sedimentary basins in this area approximately matches the magnetic (reflecting volcanic–sedimentary facies belts) map of the Avalon terrane (Haworth and LeFort, 1979) in both scale and geometry.

The volcaniclastic sediments of the Eastport basin and the succession outlined above (see Basin Fill section) bear some similiarities to a model for sedimentation in marginal arc basins synthesized by Carey and Sigurdsson (1984). For instance, pelagic muds, pyroclastic flows and dominantly mass flow epiclastic deposits displaying hydrothermal alteration, characterize the initial rifts of volcanic arcs. Rocks of the upper part of the Love Cove Group and perhaps the lower part of the Connecting Point Group (Unit C-1) have these characteristics. Initially, rift basins are generally small with steep fault-scarped margins. With continued back-arc spreading and accompanying volcanism, thick sequences of epiclastic sandy turbidites are deposited in a widening basin, which has smoother margins. Sandstone turbidites of the lower Connecting Point Group (Units C-1 to C-3), which show the evolution from a low-efficiency fan to one of improved efficiency, suggest deposition initially in a small, steep-sided basin that widened and had less precipitous slopes with time.

Plate 14. *A series of photographs that illustrate the thickening and coarsening upward of siliceous, thin- to medium-bedded turbidites of Unit C-6 at Salvage. 14a illustrates the thin planar-bedded nature of the most distal beds, which give way upward into thin-bedded, laminated and crosslaminated* T_{bc} *turbidites (14b); proximal turbidites composed of graded, massive, medium-bedded sandstones (14c) occur at the top of the sequence.*

The basin maturity and the old age stages of the Carey and Sigurdsson (1984) model are dominated by widespread pelagic sedimentation with a diminishing epiclastic turbidite component as volcanism ended and spreading ceased. The importance of pelagic sediments in stage 3 of the Eastport basin fill may partly correspond to the maturity stage. However, the transition upward into a succession of classical turbidites deposited on an actively prograding deep-water fan (stage 4) suggests that: 1) maturing of the basin was interrupted by basin extension (see stage 3), 2) renewed uplift of a source terrane (not necessarily that which supplied the older Eastport basin fill) occurred and 3) this new cycle, perhaps involving similar sediments of the Connecting Point Group of Placentia Bay and parts of the Conception Group of the eastern Avalon Zone, culminated in the shallowing upward into deltaic and fluvial sediments as the basin accreted.

SUMMARY

Volcaniclastic sediments of the Connecting Point Group and the underlying Love Cove Group possess the characteristics, composition and lithostratigraphic signature of volcanic arc basins. Pelagic and fine- to coarse-grained pyroclastic rocks, shale and related sediments, produced by sediment gravity flows having significant hydrothermal alteration, form the upper Love Cove Group and the base of the Connecting Point Group. The overlying basin fill consists of at least two packages of turbidites, separated stratigraphically by a mixtite unit. The lower package consists principally of an upward-coarsening sequence of turbidites that accumulated on a low-efficiency deep-sea fan. Such fans are typical of the deep-water volcaniclastic apron of volcanic arcs (Sigurdsson *et al.*, 1980; Carey and Sigurdsson, 1984) built up by the accumulation of large volumes of volcanic detritus. Thick, dominantly massive sand sequences are also commonly found in smaller basins where they are ponded by basin configuration and behind local barriers (Howell and Normark, 1982; Carey and Sigurdsson, 1984). The dominance of sand in the basin possibly reflects a narrow shelf between the arc and the basin, and steep gradients between source and depocentre. The steep slopes of volcanic edifices and the lack of vegetation on the Precambrian slopes facilitated the rapid production and movement of sand-sized material into the basin.

The presence of a well-developed levee-channel sequence in the upper part of the lower basin fill suggests that the sediment distribution capacity of the fan improved as the basin was infilled. This may reflect basin enlargement and gentler slopes. The lenticular nature of the channel-sand deposits in the fine, thin-bedded levee deposits suggests that channel avulsion was the principle mechanism by which sediment was distributed throughout the fan. However, the fining-upward sequences in some of the overbank sediment implies the channels must have also accreted laterally.

The mixtite that separates the two successions is interpreted as an olistostrome that formed when unconsolidated sediment of slope and basin collapsed and was transported farther into the basin. Its widespread distribution in the east of the area suggests that the mixtite probably was derived from the east. The locally southwestward-dipping imbrication of sediment rafts in the mixtite suggest, however, that in places the flow was moving northeastward immediately prior to deposition.

For the most part, the mass flow deposit involved only remobilization of slope and basin sediments. In the northeast, however, it contains scattered to common felsic volcanic and plutonic pebbles. The presence of these clasts may reflect the reworking of glacial deposits contemporaneous with the Gaskiers Formation tillite of the Conception Group (King, *in preparation*). Alternatively, it may indicate that proximal, possibly terrestrial volcanic deposits were remobilised and transported basinward by debris flows generated by the seismic activity that also triggered the submarine slides. The diabase clasts were derived from erosion of dykes that intruded the succession when the sediments were still unconsolidated.

These diabase dykes, which are common in the area northeast of Eastport, are also associated with a number of small mafic plutons. This suggests that the seismicity that may have triggered the production of the olistostrome coincided with basin extension by either basin pull-apart or by arc rifting.

The youngest basin fill above the mixtite is composed of well-developed sequences of turbidites. These rocks accumulated on deep-sea fans that were capable of efficient distribution of sediment over the submarine fan. Coarsening- and thickening-upward sequences indicate that the fans accreted by repeated progradation of suprafan lobes (Howell and Normark, 1982) on the smooth part of the fan. This upper sequence may be correlative with well-developed turbidites farther to the southwest, elsewhere in Bonavista Bay, and in the Placentia Bay area. This may indicate that the basin had enlarged with time and that its different configuration allowed the development of the classic deep-sea fan (cf. Walker, 1984).

ACKNOWLEDGMENTS

We wish to thank Erwin Wheaton and Jacob Lushman for their able assistance during the summer of 1986 and 1987. Dr. A.F. King provided helpful sedimentological and stratigraphic insights while in the field; Bryan Greene and Cyril O'Driscoll critically reviewed the manuscript.

REFERENCES

Anderson, M.M. and King, A.F.
1981: Precambrian tillites of the Conception Group on the Avalon Peninsula, southeastern Newfoundland. *In* Earth's Pre-Pleistocene Glacial Record. *Edited by* M.J. Hambrey and W.B. Harland. Cambridge University Press, pages 760-763.

Bates, R.L. and Jackson, R.L.
1987: Glossary of Geology. 3rd Edition. American Geological Institute, Alexandria, Virginia.

Bouma, A.H.
1987: Megaturbidite: An acceptable term. Geo-Marine Letters, Volume 7, pages 63-68.

Buddington, A.F.
1919: Precambrian rocks of southeast Newfoundland. Journal of Geology, Volume 27, pages 449-479.

Carey, S.N. and Sigurdsson, H.
1984: A model of volcanogenic sedimentation in marginal basins. *In* Marginal Basin Geology. *Edited by* B.P. Kokelaar and M.F. Howells. Geological Society Special Publication 16, pages 37-58.

Cook, M.E., Field, M.E. and Gardner, J.V.
1982: Characteristics of sediments on modern and ancient continental slopes. *In* Sandstone Depositional Environments. *Edited by* P.A. Scholle and D. Spearing. American Association of Petroleum Geologists, Memoir 31, pages 329-364.

Dickinson, W.R.
1974: Plate tectonics and sedimentation. *In* Tectonics and Sedimentation. *Edited by* W.R. Dickinson. Society of Economic Paleontologists and Mineralogists Special Publication 22, pages 1-27.

Fisher, R.V. and Schmincke, H.V.
1984: Pyroclastic Rocks, Springer-Verlag, 472 pages.

Haworth, R.T. and LeFort, J.P.
1979: Geophysical evidence for the extent of the Avalon Zone in Atlantic Canada. Canadian Journal of Earth Sciences, Volume 16, pages 552-567.

Hayes, A.O.
1948: Geology of the area between Bonavista and Trinity Bays, eastern Newfoundland. Geological Survey of Newfoundland, Bulletin 32, Part 1, pages 1-34.

Howell, D.G. and Normark, W.R.
1982: Sedimentology of submarine fans. *In* Sandstone Depositional Environments. *Edited by* P.A. Scholle and D. Spearing. American Association of Petroleum Geologists, Memoir 31, pages 365-404.

Hussey, E.M.
1979: Geology of the Clode Sound area, Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, 312 pages.

Hussong, D.M. and Uyeda, S.
1981: Tectonic processes in the history of the Mariana Arc: a synthesis of results of DSDP-Leg 60. *In* Initial report of the Deep-Sea Drilling Project, Volume LX, Washington, D.C., U.S. Government Printing Office, pages 909-929.

Jenness, S.J.
1963: Terra Nova and Bonavista map areas, Newfoundland (2D east half and 2C). Geological Survey of Canada, Memoir 327, 184 pages.

King, A.F.
In preparation: Late Precambrian and Quaternary geology of the St. John's area. Newfoundland Department of Mines, Mineral Development Division report (submitted for final editing).

McCartney, W.D.
1967: Whitbourne map-area, Newfoundland. Geological Survey of Canada, Memoir 341, 135 pages.

Middleton, G.V. and Hampton, M.A.
1976: Subaqueous sediment transport and deposition by sediment gravity flows. *In* Marine Sediment Transport and Environmental Management. *Edited by* D.J. Stanley and D.J.P. Swift. John Wiley and Sons, New York, pages 197-218.

Moore, R.C.
1949: The meaning of facies. Geological Society of America, Memoir 39, pages 1-34.

Normark, W.R.
1978: Fan-valleys, channels and depositional lobes on modern submarine fans: characters for the recognition of sandy turbidite environments. American Association of Petroleum Geologists, Bulletin, Volume 61, pages 912-931.

O'Brien, S.J.
1987: Geology of the Eastport (west half) map area, Bonavista Bay, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 257-270.

O'Brien, S.J. and Knight, I.
This volume: The Avalonian geology of southwest Bonavista Bay: portions of the St. Brendan's (2C/13) and Eastport (2C/12) map areas.

O'Driscoll, C.F. and Muggridge, W.W.
1979: Geology of Merasheen (1M/8) and Harbour Buffett (1M/9, east half), Newfoundland. *In* Report of Activities. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 79-1, pages 82-89.

Rose, E.R.
1952: Torbay map-area, Newfoundland. Geological Survey of Canada, Memoir 265, 64 pages.

Schermerhorn, L.J.G.
1966: Terminology of mixed coarse-fine sediment. Journal of Sedimentary Petrology, Volume 36, pages 831-835.

Sigurdsson, H., Sparkes, R.S.J., Carey, S. and Huang, T.C.
1980: Volcanogenic sedimentation in the Lesser Antilles Arc. Journal of Geology, Volume 88, pages 523-540.

Walker, R.G.
1978: Deep-water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. Bulletin of the American Association of Petroleum Geologists, Volume 62, pages 932-966.

1984: Turbidites and associated coarse clastic deposits. *In* Facies Models. *Edited by* R.G. Walker. Geoscience Canada Reprint Series 1, 2nd Edition, pages 171-188.

1985: Mudstones and thin-bedded turbidites associated with the Upper Cretaceous Wheeler Gorge conglomerates, California: a possible channel-levee complex. Journal of Sedimentary Petrology, Volume 55, pages 279-290.

Walker, R.G. and Mutti, E.
1973: Turbidite facies and facies association. *In* Turbidites and Deep Water Sedimentation. Society of Economic Paleontologists and Mineralogists, Pacific Section, Short Course Lecture Notes, Anaheim, California, pages 119-157.

Williams, H. and King, A.F.
1979: Trepassey map area, Newfoundland. Geological Survey of Canada, Memoir 389, 24 pages.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 229-245

YTTRIUM (Y) AND OTHER RARE METALS (Be, Nb, REE, Ta, Zr) IN LABRADOR

R.R. Miller
Mineral Deposits Section

ABSTRACT

The occurrence of significant rare-metal mineralization in the Strange Lake alkaline complex (Zr−Y−Nb−Be−REE) and in the Letitia Lake area (Nb−Be−Y) and the growing demand for rare metals in the 'high tech' industries has led to increased interest in rare-metal mineralization in Labrador. The study of the geology, petrography and geochemistry of known rare-metal mineralization has resulted in the development of exploration criteria that will aid further exploration in Labrador and other areas.

Mineralization in the Strange Lake deposit, the Flowers River Igneous Suite, the Mann #1, Mann #2, Michelin, Two Tom Lake and SW Ten Mile Lake showings in the Letitia Lake area and the Red Wine Alkaline Intrusive Suite (Shallow Lake area) exclusively occurs in peralkaline rocks. The following varieties of peralkaline rocks host rare-metal mineralization in Labrador: 1) granites, 2) syenites (oversaturated), 3) undersaturated intrusives and 4) trachytic and rhyolitic volcanic rocks. All of these rocks are highly evolved, and are interpreted to have been emplaced into high levels of the crust as either volcanic rocks or subvolcanic stocks.

Several modes of mineralization have been recognized in each of the different host rocks. The highest grade mineralization usually occurs as pegmatite−aplite lenses and veins, whereas lower grade−higher tonnage mineralization commonly occurs as disseminated zones within intrusive rocks or stratiform zones within volcanic rocks. The potential for the highest grades appears to be greatest in high-level intrusions that did not vent magma to the surface. This setting allowed the high concentrations of rare metals to collect in a limited area. In contrast, volcanic feeder stocks and related volcanic rocks provide a large area over which the available rare metals can be diluted rather than concentrated. When high grades of mineralization are discovered in volcanic feeder-stock settings they commonly occur within or on top of the stock.

Application of the criteria developed from the study of known rare-metal mineralization indicates that there are several unevaluated and unexplored areas of good rare-metal potential in Labrador and insular Newfoundland.

INTRODUCTION

The rare-metal elements, including Y, Be, Nb, REE, Ta, Zr, have rapidly become indispensable in the 'high tech' industries, and, as a result, the demand for these elements has been steadily increasing. This increasing demand has encouraged the exploration for economic deposits of rare metals throughout the world. Recent exploration activity in Labrador has revealed the Strange Lake deposit and several other Y-bearing showings; past exploration activity has discovered several Nb−Be showings in the Letitia Lake area. This report discusses the geology, geochemistry and setting of the rare-metal showings and deposits in Labrador to aid explorationists in discovering more of these deposits. A number of exploration targets, based on data presented in this report, will also be identified.

The 'high tech' uses of the rare metals as a group include the use of these elements in the manufacturing of: laser garnets, high temperature−high strength ceramics, superconducting materials, supermagnets, speciality steels, oil products, lamp−television phosphors and nuclear-reactor components. Many of these materials are used in the aerospace, defense, electronics and computer industries (Table 1). Generally speaking, the continuous growth in these industries is fuelling the increasing demand for new sources of the rare metals. Estimates of the increase in demand for these elements, after considering new uses and the introduction of substitute materials, ranges from 3 to 10 percent per year (US Bureau of Mines, 1985a, 1985b and 1987) up to the year 2000.

Table 2 lists the known rare-metal showings in Labrador along with a reference to previous exploration activity (MODS showing number), location, economically interesting elements, host rock, discovery date, property status, and the public source of sample analyses.

This project is a contribution to the Canada−Newfoundland Mineral Development Agreement, 1984−1989

Table 1. Some uses of the rare-metal elements

ELEMENT	MATERIAL PRODUCED	PRODUCTS MANUFACTURED
BERYLLIUM	Be metal	Aircraft components
	BeO ceramics	Electronic components Microchips and circuit boards
	Be-Cu alloys	Automobile parts Electronics Missile components
NIOBIUM	High strength, low alloy steels	Pipe for oil / gas pipelines Automobile components Drilling pipe
	Nb metal	Electronic components Carbide tools Superconductors Supermagnets Jet-Engine components
RARE EARTHS	High strength, low alloy steels	Pipe for oil / gas pipelines
	Ceramic raw material	Colouring agent Light-absorbing agent High-temperature ceramics
	Phosphors	Televison / Monitor colour tubes
	Permanent magnets	Headphones, speakers, generators, alternators, Electric motors
	Garnets	Microwave garnets Laser garnets
	Chemicals	Petroleum catalysts
	Electronics	Capacitors Cathodes and electrodes Thermisters Semiconductors
YTTRIUM	Phosphors	Television / Monitor colour tubes Fluorescent lamp tubes
	Garnets	Laser crystals Microwave crystals
	Stabillized zirconia ceramics	Cutting edges Automobile parts Tool dies
ZIRCONIUM	Refractories	Zirconium bricks Zirconium sand
	Ceramics	Oxygen sensors in furnaces Oxygen sensors in gas engines Colouring agent Electronic components Circuit boards Cutting edges Automobile parts
	Abrasives	Glass polishing compounds

Table 2. Rare-metal showings in Labrador

Name of Showing	MODS #	Location N	Location E	Elements	Host Rock/Setting	Discov. Date	Status	Analysis Ref.
Strange Lake	Zr 001 24A/8	56°18′45″	62°06′45″	Zr-Y-Nb Be-REE	Peralkaline granite pegmatite	1979	Staked I.O.C.	Miller (1986a)
Flowers River	Fsp 006 13N/11	55°35′00″	61°05′00″	Zr-Y-Nb	Peralkaline granite/ Felsic volcanics	1977	Unstaked	Hill (1981, 1982)
Mann #1	Be 001 13L/1	54°14′00″	62°24′00″	Be-Nb	Peralkaline syenite/ Comenditic volcanics	1956	Cuvier	Dujardin (1961)
Michelin	Nb 002 13L/1	54°14′00″	62°27′00″	Be-Nb	Peralkaline syenite/ Comenditic volcanics	1956	Unstaked	Miller (1986b)
Mann #2	Nb 001 13L/1	*54°13′00″	62°27′00″	Be-Nb	Peralkaline syenite/ Comenditic volcanics	1956	Unstaked	Miller (1986b)
Two Tom Lake	REE 001 13L/1	54°13′00″	62°09′00″	Be-Nb-Y	Peralkaline syenite/ Comenditic volcanics	1967	ASARCO	Batterson and Miller (1987)
SW Ten Mile Lake	REE 001 13L/2	54°14′30″	62°31′00″	Y	Peralkaline syenite ?	1985	Unstaked	Miller (1986b)
Red Wine Suite	Zr 001 13L/2	*not located	not located	Y-Zr	Undersaturated peralkaline complex	1972	Unstaked	Curtis and Currie (1981)

* many small showings in the vicinity MODS–Department of Mines Mineral Inventory File Numbers

The Strange Lake deposit (Figure 1) and the Mann #1 showing (Letitia Lake area, Figure 1) are the only properties for which there is some estimate of tonnage and grade, although the Mann #1 property reserves are not well known. Poorly evaluated showings and occurrences that contain interesting quantities of rare metals include:

Flowers River occurrence (Flowers River Igneous Suite)
Mann # 2 showing (Letitia Lake area)
Michelin # 1 showing (Letitia Lake area)
Two Tom Lake showing (Letitia Lake area)
SW Ten Mile Lake occurrence (aegirine gneiss; Letitia Lake)
Red Wine North occurrence (Shallow Lake area)

The Flowers River, SW Ten Mile Lake and Red Wine North occurrences consist of anomalous values of rare metals, including Y, in a small number of grab samples (< 3 samples). All known rare-metal deposits and showings in Labrador, with the exception of the Strange Lake deposit, have not been properly evaluated.

In this paper, the mineralization and host rocks at each of the properties listed in Table 2 are examined to help develop exploration criteria for rare-metal deposits in Labrador. In most cases, geochemical data for mineralization and host rocks are known, as are the geology, style of mineralization and geological settings. Plans, cross-sections and geochemical tables are used to present this data.

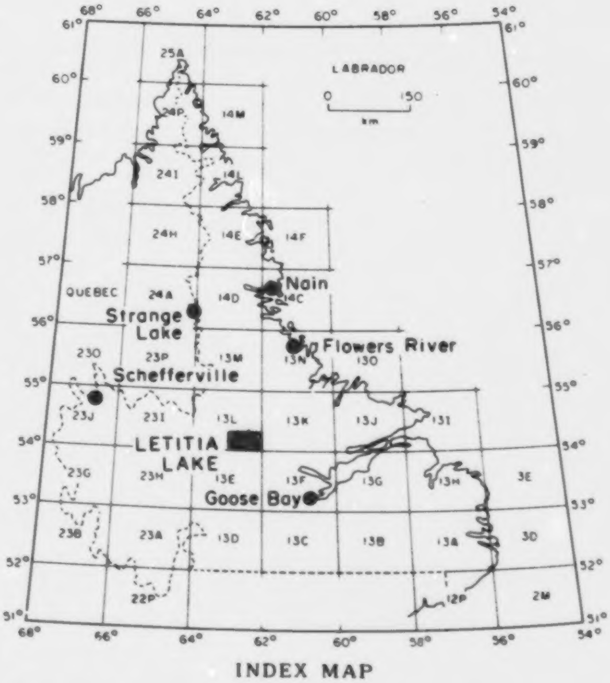

LABRADOR
0 150
km
QUEBEC
Strange Lake
Nain
Flowers River
Schefferville
LETITIA LAKE
Goose Bay
25A
24P
14M
24I
14L
24H
14E
14F
24A
14D
14C
23O
23P
13M
13N
13O
23J
23I
13L
13K
13J
13I
23G
23H
13E
13F
13G
13H
3E
23B
23A
13D
13C
13B
13A
3D
22P
12P
2M
68°
66°
64°
62°
60°
58°
56°
54°
61°
60°
59°
58°
57°
56°
55°
54°
53°
52°
51°
INDEX MAP

Figure 1. *Location of the Letitia–Shallow lakes area, Flowers River area and the Strange Lake deposit.*

DEPOSIT–SHOWING–OCCURRENCE DESCRIPTIONS

Strange Lake Deposit

Introduction. The Strange Lake alkaline complex, which hosts the Strange Lake deposit, is located on the Quebec–Labrador boundary approximately 250 km northeast of Schefferville, Quebec, and 150 km west of Nain, on the Labrador coast (Figure 1). It consists of three major phases of aegirine–riebeckite-bearing, peralkaline granite. Extensive drilling within the complex, by the Iron Ore Company (Venkatswaran, 1983) from 1979 to 1983, has outlined one deposit having approximately 50 million tonnes of Zr–Y–Nb–Be–REE mineralization.

Geology. The peralkaline granite phases are characterized by varying amounts of exotic minerals (e.g., elpidite, armstrongite, gittinsite, gadolinite, zircon, astrophyllite, fluorite, titanite), most of which contain important concentrations of rare metals. Each granitic phase has similar textural variants (i.e., pegmatitic, medium grained, porphyritic, fine grained, inclusion-bearing; Miller, 1986a). The three major phases are called exotic-poor, exotic and exotic-rich in order of increasing exotic-mineral and rare-metal contents, and in order of decreasing age. Figure 2 illustrates the distribution of the major phases within the complex in a plan view, whereas Figure 3 illustrates the relationships in a north-south cross-section.

All contacts are sharp and there is little or no obvious metasomatism of host rocks at the contacts. The complex is roughly circular in plan and is encircled by a ring fault (outward dips of 20 to 35°) that occurs at or near the contact of the granite and the host rocks (Miller, 1986a).

Table 3 lists the major- and minor-element contents of representative samples of each of the major, and some of the minor, variants in the Strange Lake complex.

Mineralization. All of the mineralization occurs in exotic-rich granite, the youngest phase of the complex. As illustrated by Figure 3, the mineralization occurs in a small stock or subsidiary intrusion at the contact between the two other major phases in the complex. The exotic-rich stock occurs over an approximately 2 km² area. Representative analyses are listed under 'exotic-rich' phase in Table 3.

High-grade zones within the exotic-rich stock (Figure 4) occur as:

1) pegmatite–aplite lenses that intrude the exotic phase,

2) pegmatite–aplite lenses and zones at or near the upper and lower contacts of the exotic-rich stock,

3) pegmatite veins cutting the medium grained variant, which is the major rock type within the stock, and

4) small veins, mostly pegmatitic, cutting the exotic-poor phases.

The most mineralized and economically interesting mineralized zones are the occurrences of pegmatite or pegmatite–aplite zones, which are characterized by high concentrations of rare metals (Table 3) and high radioactivity. Larger tonnages of medium-grade mineralization occur as disseminated mineralization in the medium grained exotic-rich stock.

Published reserve figures (Venkatswaran, 1983) indicate that this mineralized stock contains reserves of approximately 52,000,000 metric tons grading 2.93% ZrO_2, 0.31% Y_2O_3, 0.38% Nb_2O_5, 0.54% REE and 0.08% BeO; all reserves can be recovered by open pit mining. There is a high grade zone within this reserve (tonnages not published to date), which contains 3.25% ZrO_2, 0.66% Y_2O_3, 0.56% Nb_2O_5, 1.30% REE and 0.12% BeO (Dawe, 1984). The analyses of representative samples of the exotic phase of the granite indicate that ZrO_2 values of 2% and Y_2O_3 values of 0.25% are common (Table 3).

Setting. The Strange Lake complex occurs at the contact of relatively unmetamorphosed quartz monzonite (adamellite) to the south and east, and a metamorphic suite of mainly intrusive rocks to the north and south. An age date of 1189 ± 32 Ma (Rb–Sr wholerock, Duthou *et al.*, 1986) for the peralkaline granite and the lack of metamorphic textures indicate that it is postmetamorphic (post-Elsonian metamorphism–Neohelikian in age). Crosscutting relationships indicate that it is younger than the surrounding host rocks.

Abundant evidence indicates that the complex is a high-level pluton that has intruded into cold crust. The major evidence sited in favour of this conclusion is:

1) the occurrence of abundant discrete inclusions of host rock and peralkaline granite; inclusions exhibit only minor alteration,

2) the abundance of fine- to very fine-grained textural varieties (< 0.5 mm), particularly in the outer and upper portions of the complex,

3) the presence of a ring fault that completely circles the complex; similar to those of the subvolcanic–volcanic complexes in Nigeria (Jacobson *et al.*, 1958),

4) the occurrence of fine grained porphyritic rocks, and

5) the presence of primary microperthitic feldspars.

Most of this evidence suggests rapid cooling of the granite magma in a near surface environment.

There is very little direct evidence to indicate whether or not volcanic rocks were produced from the Strange Lake magma system. Aside from the very fine grained, exotic-poor phase, there are no observed phases which have the grain size or characteristics of volcanic rocks. Veins of the very fine grained phase crosscutting host rocks indicate that at least

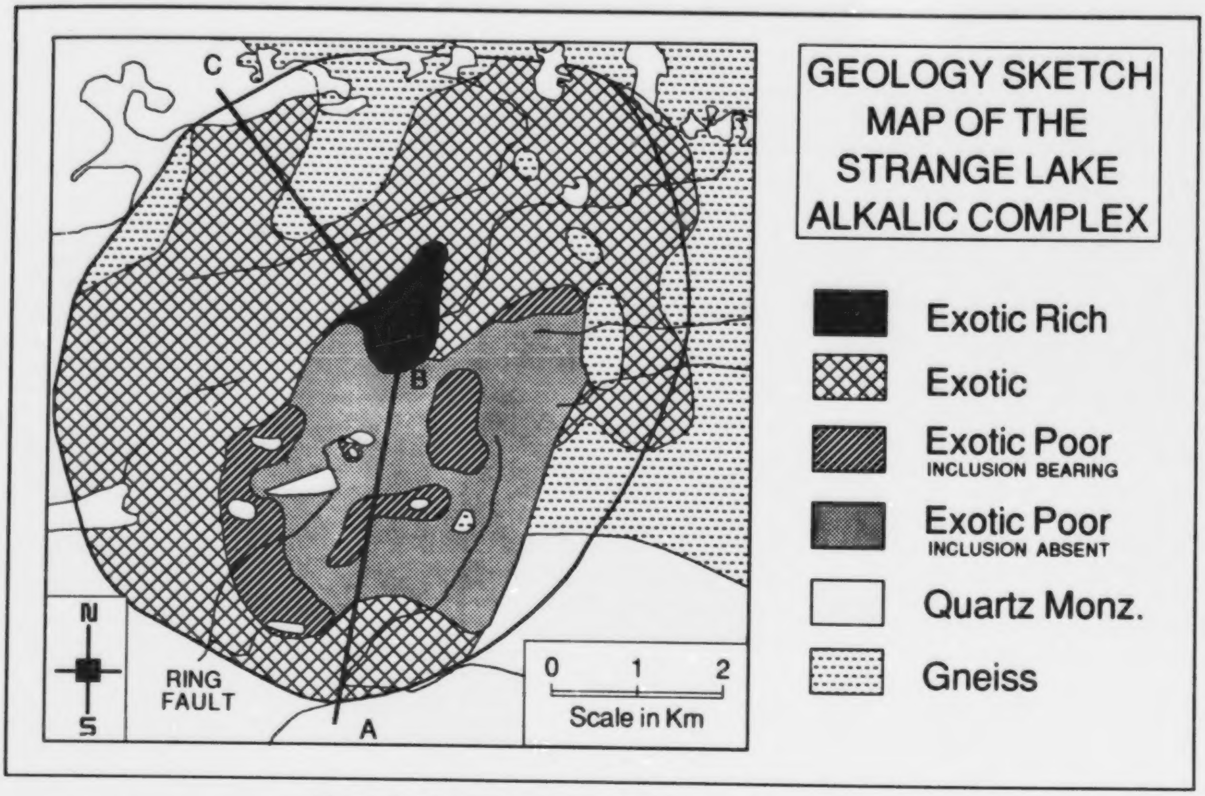

GEOLOGY SKETCH MAP OF THE STRANGE LAKE ALKALIC COMPLEX
Exotic Rich
Exotic
Exotic Poor INCLUSION BEARING
Exotic Poor INCLUSION ABSENT
Quartz Monz.
Gneiss
C
B
A
N
S
RING FAULT
0 1 2
Scale in Km

Figure 2. *General geology of the Strange Lake complex.*

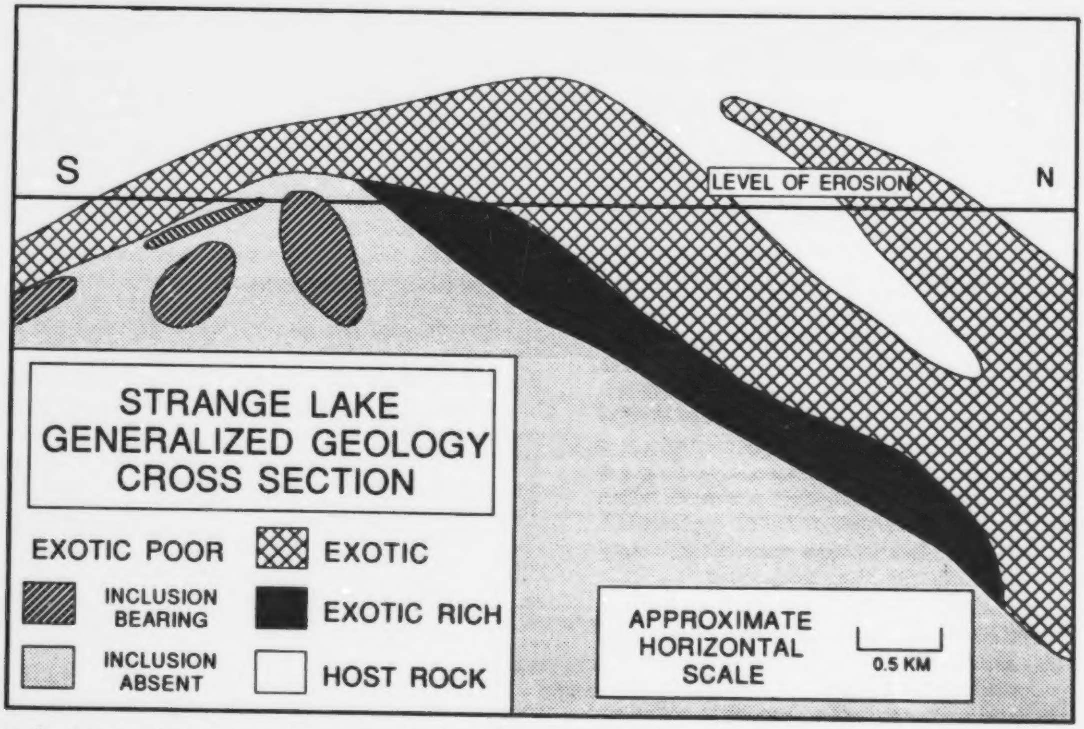

S
N
LEVEL OF EROSION
STRANGE LAKE GENERALIZED GEOLOGY CROSS SECTION
EXOTIC POOR
INCLUSION BEARING
INCLUSION ABSENT
EXOTIC
EXOTIC RICH
HOST ROCK
APPROXIMATE HORIZONTAL SCALE
0.5 KM

Figure 3. *Interpretive north-south cross-section through the Strange Lake complex; see Figure 2 for the location of the section line A-B-C.*

Table 3. Major- and minor-element analyses of representative samples from the Strange Lake complex

	EXOTIC POOR					EXOTIC		EXOTIC RICH		
	SL-84017 Inclusion	SL-84273 Inclusion	SL-84090 Fine Grained	SL-84011 Medium Grained	SL-84071 Medium Grained	SL-84266 Porphyritic	SL-84210 Medium Grained	SL-84280 Fine Grained	SL-84270 Pegmatitic	SL-84108 Fine Grained
SiO_2	69.95	69.75	70.45	71.05	72.60	70.30	75.45	71.60	67.20	64.10
TiO_2	0.16	0.28	0.24	0.28	0.25	0.40	0.27	0.29	0.08	0.79
Al_2O_3	12.52	11.89	11.78	11.34	10.21	9.70	8.07	9.23	5.07	4.42
Fe_2O_3	1.50	2.02	3.68	1.72	1.91	2.61	2.40	2.67	2.43	4.78
FeO	2.58	2.45	0.31	3.09	2.72	2.57	1.09	1.89	0.01	1.48
MnO	0.07	0.14	0.06	0.10	0.12	0.17	0.15	0.11	0.15	0.32
MgO	0.04	0.14	0.03	0.02	0.09	0.30	0.09	0.02	1.31	1.65
CaO	0.79	1.21	1.11	0.39	0.22	1.87	1.40	1.39	8.05	5.08
Na_2O	4.93	4.54	6.61	5.49	4.91	4.29	2.78	4.82	0.55	2.88
K_2O	6.26	5.88	3.72	4.54	4.57	4.02	4.24	3.41	4.27	0.59
P_2O_5	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.14
ZrO_2	0.39	0.73	0.68	0.77	0.89	1.86	2.33	2.17	0.61	3.03
Y_2O_3	0.10	0.12	0.07	0.08	0.21	0.27	0.37	0.32	2.02	1.58
Nb_2O_5	0.03	0.05	0.06	0.04	0.13	0.15	0.16	0.15	0.18	2.00
BeO	0.01	0.01	0.01	0.01	0.05	0.04	0.04	0.06	1.45	0.40
H_2O	0.11	0.04	0.50	0.37	0.68	0.47	0.50	0.50	2.23	3.28
CO_2	0.05	0.03	0.13	0.10	0.12	0.04	0.01	0.11	0.10	0.26
F	0.59	0.42	0.65	0.38	0.20	0.63	0.45	0.77	3.32	1.77
F=O	-0.25	-0.18	-0.27	-0.16	-0.08	-0.27	-0.19	-0.32	-1.40	-0.74
Total	99.84	99.53	99.84	99.63	99.82	99.45	99.64	99.23	97.67*	97.81*
U	7.7	16.7	21.9	18.3	29.7	50.2	52.6	65.7	134.0	252.0
Th	32	47	91	101	134	163	227	375	2572	4884
Rb	774	1262	531	524	1074	1310	987	960	758	142
Sr	15	31	48	3	9	72	35	22	266	673
Zn	342	753	365	432	903	803	1005	947	1681	1553

Notes: All oxides and F in Weight %; trace elements quoted as ppm. Major elements, Be, and Zn were analysed by A.A. method (Nfld. Dept. of Mines); F by Specific Ion Electrode Method and CO_2 + H_2O by I.R. Method (Nfld. Dept. of Mines); Th, Rb, Sr, Y, Zr, Nb by XRF method (Memorial University XRF Lab.); U by neutron activation (Nuclear Activation Services Ltd.).

* Samples contain 2-3% REE.

some of this exotic-poor phase has a pluton chill margin, rather than a volcanic, setting. Indirect evidence, such as the extreme concentration of rare metals and other incompatible elements in the late stages of the complex, suggest that there was no tapping of the magma chamber to bring incompatible-element-laden volatiles to the surface. Fluorite vein breccias within the ring fault are the only example of extensive host rock-veining brecciation, yet they are extremely deficient in rare metals, suggesting a closed system for rare metals within the granite magma chamber. It appears that the apparent lack of volcanism in this case contributed to the concentration of rare metals in the exotic-rich (i.e., late) phase.

There are no obvious structural controls on the location of the Strange Lake complex. Although peralkaline granites are often associated with rift zones and crustal upwelling there is no obvious evidence of faulting near the Strange Lake complex (B. Ryan, personal communication, 1986).

Flowers River Igneous Suite

Introduction. The Flowers River Igneous Suite (Hill, 1982) occupies an area of approximately 1700 km² in the Flowers River area on the coast of northern Labrador, 250 km north of Goose Bay (Figure 1). It consists of a peralkaline, amphibole–pyroxene granite batholith, several satellite, peralkaline granite plutons and an overlying sequence of peralkaline, rhyolitic pyroclastic rocks and flows. There has been no recorded rare-metal exploration activity in this vicinity although reports on the geochemistry of the volcanics of the complex (Hill, 1982) indicate Y values up to 500 ppm and Zr up to 4000 ppm. The analysis of a granite dyke in the complex yielded the following encouraging values: 1020 ppm Nb, 2233 ppm Y and 20,594 ppm Zr (Hill, 1982).

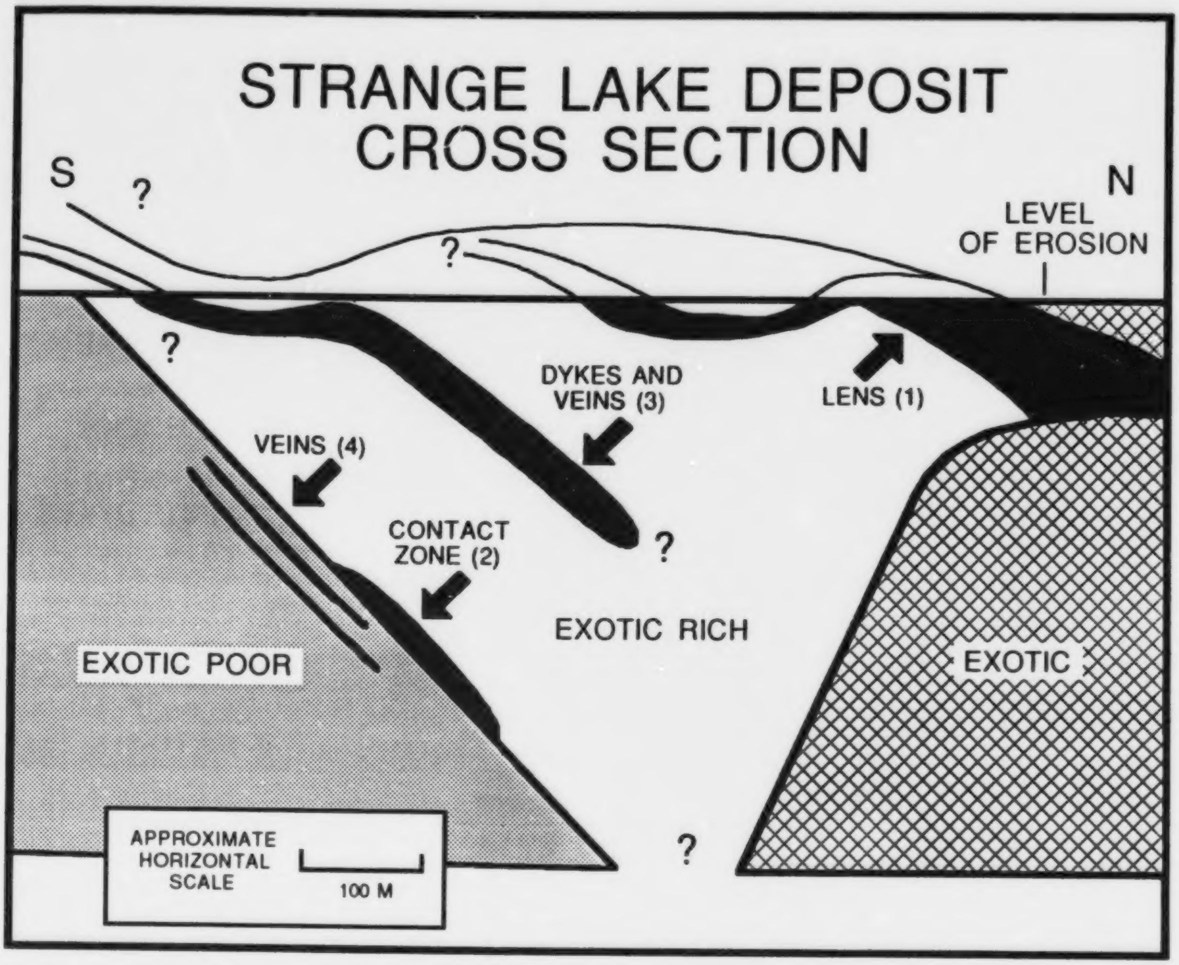


Figure 4. *Interpretive north-south cross-section through the main rare-metal zone in the Strange Lake complex; the various types of mineralization, as indicated by the numbers in brackets, are described in the text.*

Geology. Hill (1982) reported four main textural varieties of felsic volcanic rocks within the Flowers River suite: massive porphyry, felsite, tuffaceous pyroclastics and breccia; most consist mainly of quartz and feldspar with no primary mafic minerals. All contain aphanitic or fine grained matrices. The felsite, tuffs and porphyries grade into each other through the variation in quartz–feldspar phenocryst content and the presence or absence of flow banding. These rocks represent flows, pyroclastics and subvolcanic feeder dykes.

The peralkaline granites are characterized by riebeckite–arfvedsonite, aegirine, quartz and perthite. Accessory minerals include aenigmatite, astrophyllite, opaques, fluorite, zircon, allanite and apatite. Textures range from fine- to coarse-grained and are typically massive and equigranular; related aplitic and pegmatitic peralkaline granite dykes are also present.

Figure 5 is a plan view of the geology of the Flowers River suite. The volcanic suite occurs as a centrally located unit within the the main peralkaline granite batholith. Topographic considerations indicate that the volcanics are structurally higher than the granite. Hill (1982) reported outcrops in which granitic roof rocks pass gradationally upward into compositionally similar volcanic rocks. Crosscutting relationships indicate that the granite is younger than the volcanics. Flow-banding measurements suggest that the volcanics occupy a depression in the roof of the granite batholith.

Table 4 lists the major- and minor-element analyses of representative samples of the various units in the Flowers River suite as well as average values of the peralkaline granites and felsic volcanics as calculated by Hill (1982).

Mineralization. The only economically significant rare-metal mineralization reported from the Flowers River area is the partial analysis of a peralkaline granite dyke, containing 10 percent fluorite, reported by Hill (1981, 1982; reprinted in Table 4). The extent, location and mineralogy of this dyke

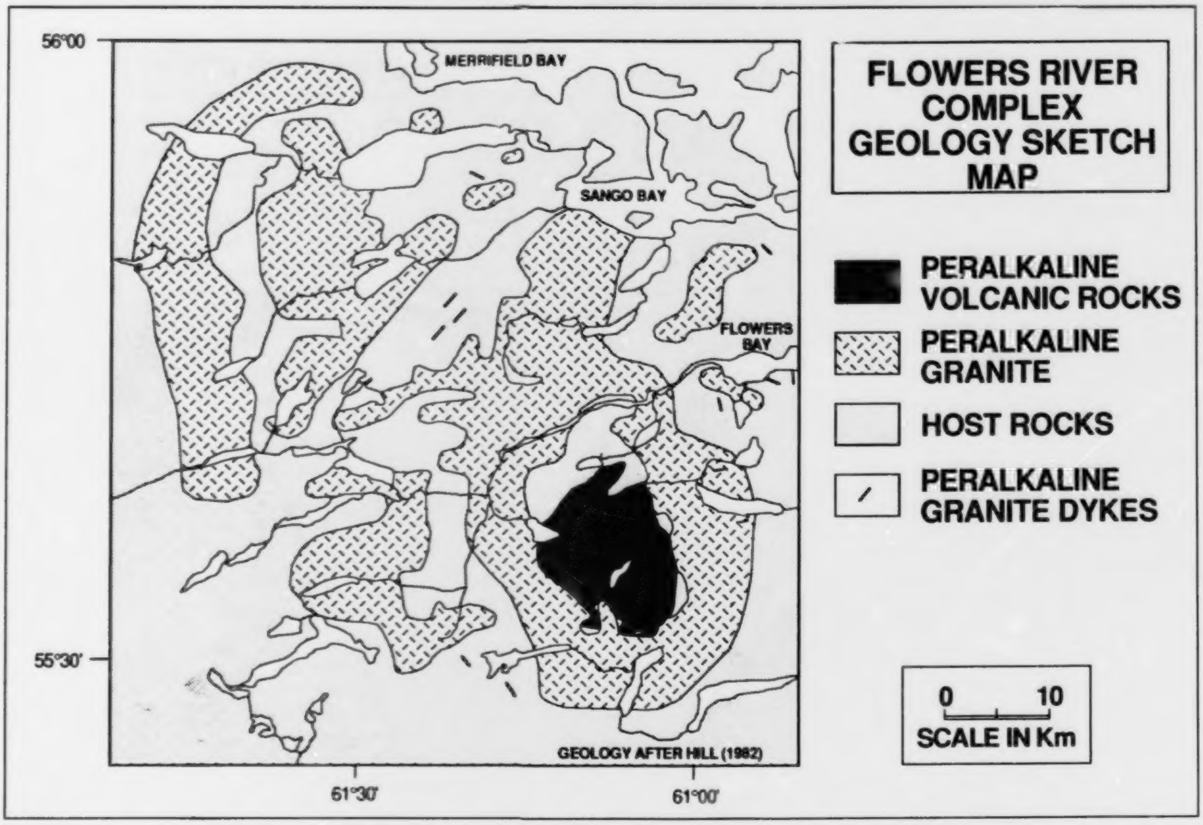

56°00'
55°30'
61°30'
61°00'
MERRIFIELD BAY
SANGO BAY
FLOWERS BAY
GEOLOGY AFTER HILL (1982)
FLOWERS RIVER COMPLEX GEOLOGY SKETCH MAP
PERALKALINE VOLCANIC ROCKS
PERALKALINE GRANITE
HOST ROCKS
PERALKALINE GRANITE DYKES
0
10
SCALE IN Km

Figure 5. *General geology of the Flowers River Igneous Suite (after Hill, 1982).*

Table 4. Major- and minor-element analyses of representative samples from the Flowers River Igneous Suite

	JH-77-066 Porphyry	JH-77-071A Porphyry	JH-77-361 Felsite	JH-77-330 Tuff	JH-77-040 Granite	JH-77-153 Granite	JH-77-298A Granite	JH-77-592D Granite	JH-77-076 Dyke	JH-77-423B Dyke
SiO_2	77.54	73.15	76.68	73.02	74.30	74.60	73.60	75.90	73.13	–
TiO_2	0.33	0.38	0.28	0.45	0.36	0.36	0.48	0.25	0.23	–
Al_2O_3	11.88	11.14	9.39	10.11	12.05	11.65	11.60	10.70	10.30	–
Fe_2O_3	0.88	1.64	0.75	7.27	–	–	–	–	2.32	–
FeO	2.24	7.58	4.98	1.69	2.79	3.19	4.22	3.25	2.44	–
MnO	0.03	0.05	0.04	0.05	0.04	0.04	0.05	0.04	0.09	–
MgO	0.08	0.11	0.03	0.00	0.05	0.03	0.11	0.02	0.20	–
CaO	0.11	0.19	0.11	0.23	0.53	0.53	0.67	0.27	0.63	–
Na_2O	0.02	0.65	0.02	0.27	4.13	4.07	4.15	4.12	4.63	–
K_2O	5.00	1.72	2.62	5.46	5.12	5.01	4.85	4.78	4.51	–
P_2O_5	0.00	–	0.00	–	–	–	–	–	–	–
H_2O	1.66	3.17	2.43	1.13	0.44	0.58	0.12	0.47	0.72	–
CO_2										
F	0.12	–	–	0.38	0.16	0.16	0.02	0.16	–	–
F=O	-0.05	–	–	-0.16	-0.07	-0.07	-0.01	-0.07	–	–
Total	99.84	99.78	97.33	99.90	99.90	100.15	99.86	99.89	99.20	–
Zr	1090	1967	7072	4717	691	614	835	1138	1764	20594
Y	100	231	547	489	116	122	103	147	315	2233
Nb	43	91	264	151	91	61	47	140	163	1020
Be	–	–	–	–	–	–	–	–	–	–
U	–	–	–	–	3.0	2.0	2.0	–	–	–
Th	–	–	–	–	26	20	12	–	–	–

Notes: All oxides and F in Weight %; trace elements quoted as ppm.
H_2O is Loss on Ignition.
Analyses from Hill (1982).

was not reported. The occurrence of such high values of Y, Zr, and Nb in a grab sample certainly suggests a rare-metal potential for the suite. Further examination of the rare-metal contents of the representative analyses of rocks from the suite indicates that the volcanics generally contain the highest values of Y and Zr, whereas the granites and dyke rocks contain lower values.

Setting. The Flowers River suite intrudes the southeast corner of the Paleohelikian Nain Plutonic Suite and also intrudes Aphebian gneisses. Age relationships indicate that the peralkaline rocks are not genetically related to these spatially related rocks. An age date reported by Hill (1982) gives a Neohelikian age of 1270 ± 14 Ma for the Flowers River peralkaline granite.

The spatial relationships of the peralkaline volcanic rocks and peralkaline granite indicate that the suite consists of a subvolcanic batholith that crosscuts coeval, cogenetic subaerial volcanics. The chemical and mineralogical relationships are not as clear cut because the volcanic rocks contain much lower concentrations of sodium and do not contain peralkaline mafic minerals. Yet, the work of Hill and Thomas (1983) clearly indicates that the Flowers River volcanic rocks are peralkaline in nature and are thus related to the granites. The chemical differences have been attributed to postmagmatic processes (Hill and Thomas, 1983).

Letitia–Shallow Lakes Area

Introduction. The Letitia–Shallow lakes area is located in the Central Mineral Belt of Labrador 160 km northwest of Goose Bay (Figure 1). Nb–Be showings have been known in this area for more than 30 years. The largest of these, the Mann #1 showing, contains an estimated 2 million short tons of 0.35–0.40 percent BeO and 0.24 percent Nb_2O_5 in one mineralized zone (Dujardin, 1961). Recent work by Miller (1986b) and Batterson and Miller (1987) has also revealed the potential for Y mineralization in the area as well.

The rare-metal showings in this area are associated with peralkaline syenites of the Red Wine Alkaline Intrusive Suite (Thomas, 1980) and volcanic rocks of the Letitia Lake Group (Figures 6 and 7). In most cases, aegirine–riebeckite syenite dykes or plutons (± quartz) are associated with the mineralization, which is hosted within the syenite or nearby trachytic volcanic rocks. In one case, anomalous rare-metal values are found within undersaturated syenites and nepheline syenites of the the Red Wine suite. The volumetrically important quartz–feldspar porphyries and rhyolitic flows of the Letitia Lake Group appear to be devoid of significant mineralization.

As mentioned earlier and in Table 2, several showings of interest will be discussed; Red Wine North occurrence, SW Ten Mile Lake occurrence, Two Tom Lake showing, Michelin # 1 showing, Mann # 1 and Mann # 2 showings.

Geology. The general geology of the Letitia and Shallow lakes area is outlined on Figure 6 and 7, and the stratigraphy of the area is outlined in Figure 8. The peralkaline rocks of interest are part of the Letitia Lake Group volcanics and volcanogenic sediments, and part of the Red Wine suite. The Letitia Lake Group is underlain by the North Pole Brook Intrusive Suite, to the south and east, and is unconformably overlain by the subaerial sedimentary and volcanic rocks of the Seal Lake Group to the north and west. The Red Wine suite intrudes the Letitia Lake Group or, locally, it intrudes the North Pole Brook Intrusive Suite near the lower contact of the Letitia Lake Group.

The Letitia Lake Group has been subdivided into three stratigraphic units:

1) a lower unit of quartz - feldspar porphyries (oldest),

2) a middle unit of rhyolitic flows and pyroclastic rocks, and

3) an upper unit consisting of trachytic–comenditic volcanics in its lower portions and volcanogenic sediments in its upper portions.

The chemistry of the first two units has been reported by Thomas (1980); representative analyses from his report and the present study are presented in Table 5. Analyses for some volcanics from the upper unit are listed in Table 6.

The quartz and quartz–feldspar porphyries of the lower unit are massive rocks which may be flows or subvolcanic feeder dykes. As in the volcanic rocks of the Flowers River Igneous Suite, many rocks in this unit contain few or no peralkaline mafic minerals.

Middle unit volcanic rocks east of the Mann #1 showing also have few or no peralkaline minerals; their mineralogy is dominated by quartz and feldspar. Outcrops to the west of the Mann #1 showing, however, commonly contain abundant peralkaline minerals. This dichotomy suggests that there may be some problems with the present assignment of rocks to the middle unit.

There are three main varieties of volcanic rocks in the upper unit:

1) massive to amygdular, fine grained (< 0.2 mm) aegirine-bearing,

2) banded, tuffaceous(?) aegirine–riebeckite bearing (< 0.5 mm), and

3) feldspar-porphyritic aegirine–riebeckite bearing (< 0.5 mm).

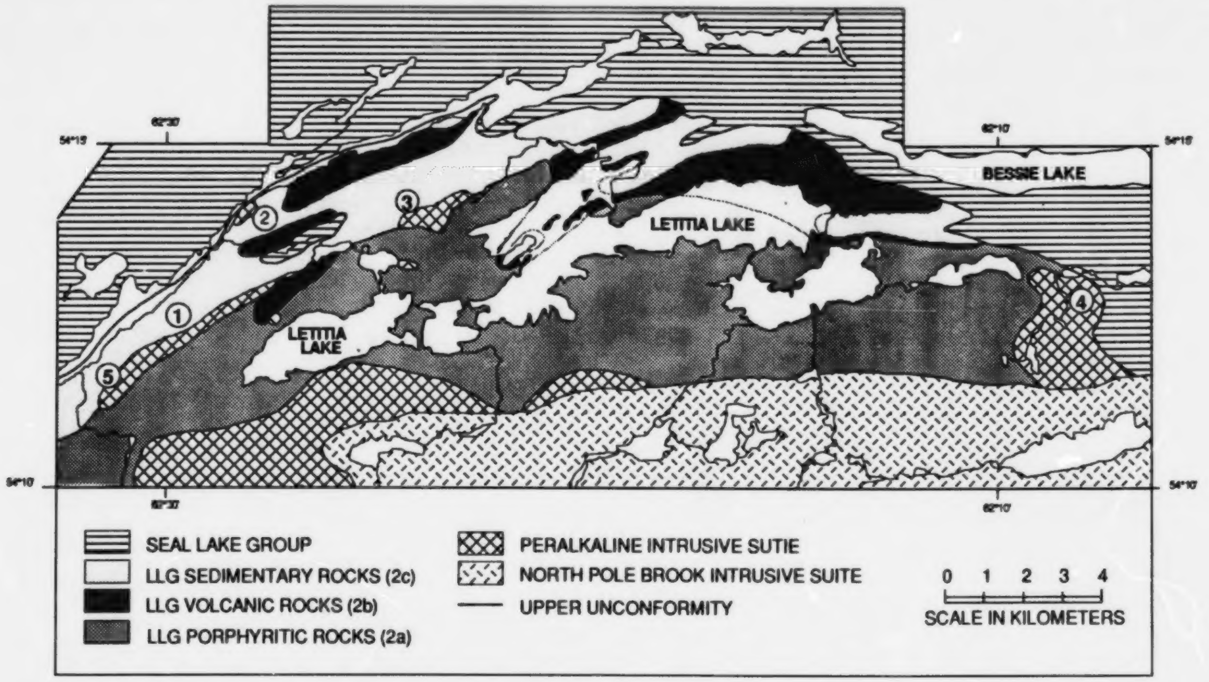

62°30'
62°10'
54°15'
54°15'
54°10'
54°10'
BESSIE LAKE
LETITIA LAKE
LETITIA LAKE
①
②
③
④
⑤
SEAL LAKE GROUP
LLG SEDIMENTARY ROCKS (2c)
LLG VOLCANIC ROCKS (2b)
LLG PORPHYRITIC ROCKS (2a)
PERALKALINE INTRUSIVE SUTIE
NORTH POLE BROOK INTRUSIVE SUITE
UPPER UNCONFORMITY
0 1 2 3 4
SCALE IN KILOMETERS

Figure 6. *Generalized geology of the Letitia Lake area. The numbered localities are the main rare-metal showings in this area: 1–Mann #2; 2–Michelin; 3–Mann #1; 4–Two Tom Lake; 5–SW Ten Mile Lake. LLG–Letitia Lake Group. Modified from Thomas (1981)*

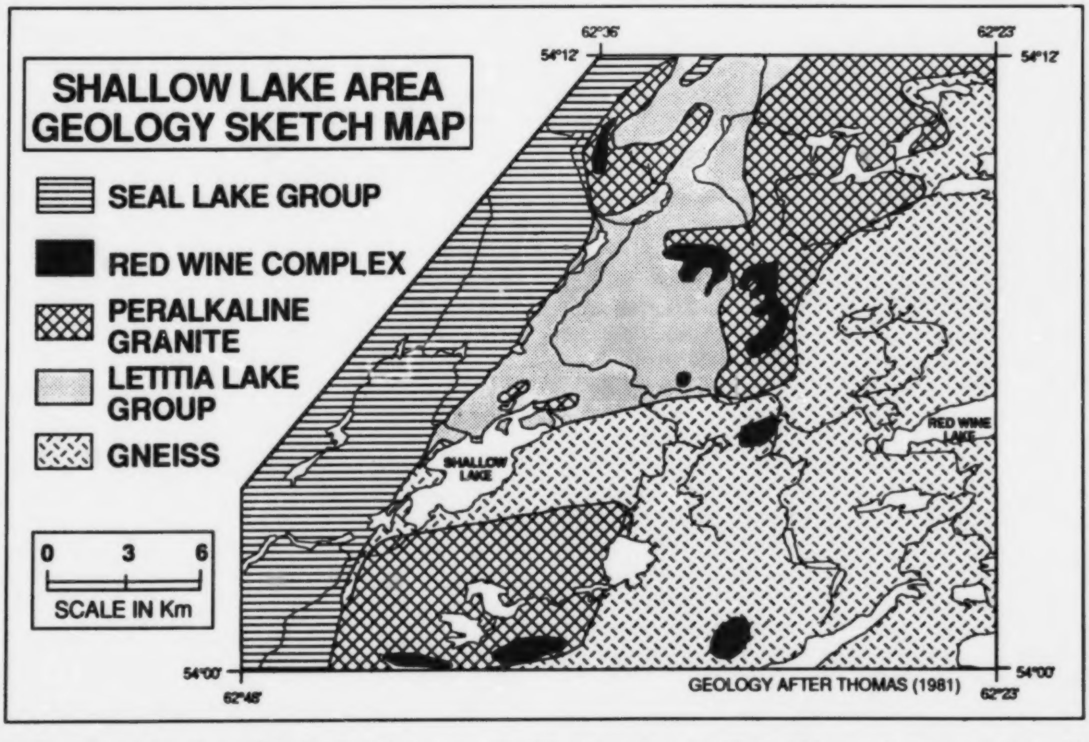

SHALLOW LAKE AREA
GEOLOGY SKETCH MAP
SEAL LAKE GROUP
RED WINE COMPLEX
PERALKALINE GRANITE
LETITIA LAKE GROUP
GNEISS
0 3 6
SCALE IN Km
62°36'
62°23'
54°12'
54°12'
54°00'
54°00'
62°48'
62°23'
SHALLOW LAKE
RED WINE LAKE
GEOLOGY AFTER THOMAS (1981)

Figure 7. *General geology of the Shallow Lake area. Modified from Thomas (1981). This area is 1 km southwest of the area depicted in Figure 6.*

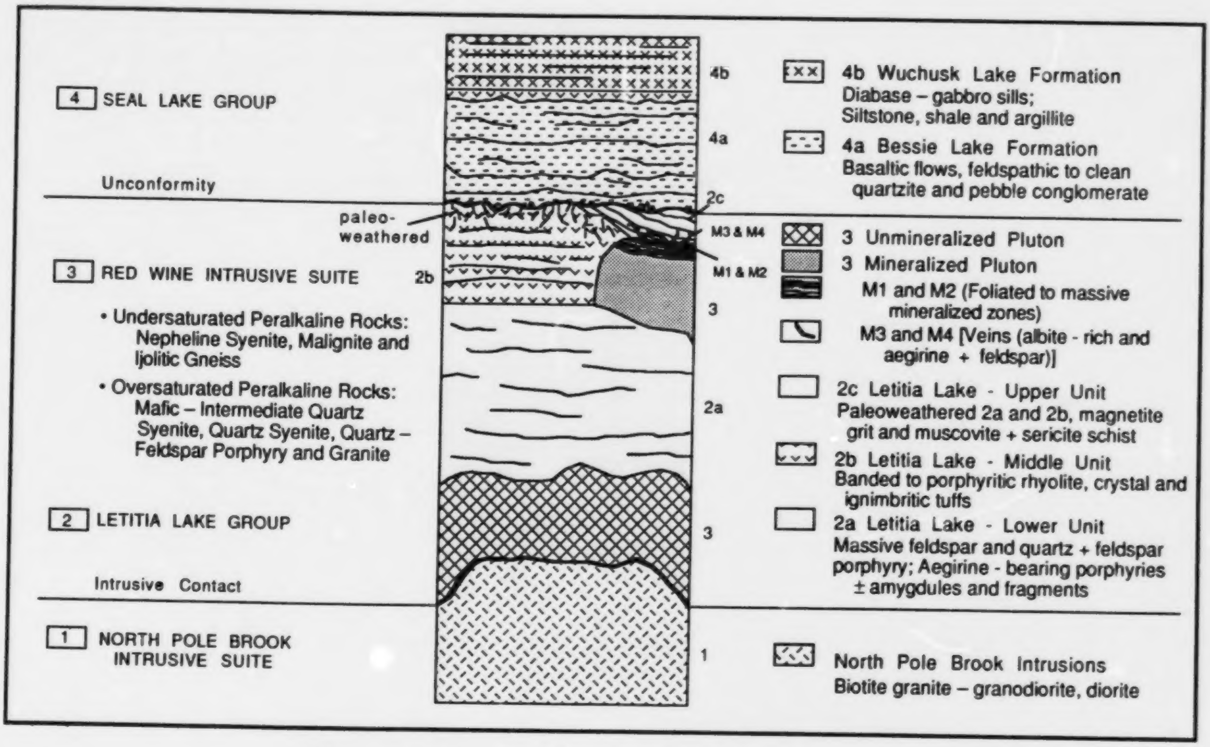

4 SEAL LAKE GROUP
Unconformity
paleo-weathered
3 RED WINE INTRUSIVE SUITE
• Undersaturated Peralkaline Rocks: Nepheline Syenite, Malignite and Ijolitic Gneiss
• Oversaturated Peralkaline Rocks: Mafic – Intermediate Quartz Syenite, Quartz Syenite, Quartz – Feldspar Porphyry and Granite
2 LETITIA LAKE GROUP
Intrusive Contact
1 NORTH POLE BROOK INTRUSIVE SUITE
4b
4a
2c
M3 & M4
M1 & M2
2b
3
2a
3
1
4b Wuchusk Lake Formation
Diabase – gabbro sills; Siltstone, shale and argillite
4a Bessie Lake Formation
Basaltic flows, feldspathic to clean quartzite and pebble conglomerate
3 Unmineralized Pluton
3 Mineralized Pluton
M1 and M2 (Foliated to massive mineralized zones)
M3 and M4 [Veins (albite - rich and aegirine + feldspar)]
2c Letitia Lake - Upper Unit
Paleoweathered 2a and 2b, magnetite grit and muscovite + sericite schist
2b Letitia Lake - Middle Unit
Banded to porphyritic rhyolite, crystal and ignimbritic tuffs
2a Letitia Lake - Lower Unit
Massive feldspar and quartz + feldspar porphyry; Aegirine - bearing porphyries ± amygdules and fragments
North Pole Brook Intrusions
Biotite granite – granodiorite, diorite

Figure 8. *General stratigraphy of the Letitia Lake area.*

Table 5. Major- and minor-element analyses of representative samples from the Letitia Lake Group volcanic rocks

	LL–84014 Aegirine -rich	LL–86021 Feldspar Porphyry	LL–84082 Feldspar Porphyry	LL–85018 Feldspar Porphyry	LL–85072 Very Fine Grained Flow	LL–85063 Feldspar Porphyry	LL–86013 Quartz-Feldspar Porphyry	LL–86014 Quartz-Feldspar Porphyry	T78-03 Crystal Tuff	T78-21 Ash Flow Tuff
SiO_2	57.95	64.45	65.15	60.65	68.15	69.55	74.65	76.40	74.40	78.90
TiO_2	1.38	0.83	0.74	0.75	0.28	0.64	0.27	0.29	0.35	0.25
Al_2O_3	10.98	13.86	10.00	11.75	12.79	11.64	10.87	10.11	9.70	9.40
Fe_2O_3	5.09	3.12	9.43	9.47	4.79	2.38	2.10	1.18	1.20	1.13
FeO	4.84	2.65	0.07	1.43	0.10	3.24	0.75	1.70	3.03	1.44
MnO	0.55	0.12	0.20	0.28	0.45	0.10	0.06	0.04	0.15	0.04
MgO	2.35	0.86	0.13	0.21	0.03	0.32	0.10	0.06	0.19	0.10
CaO	4.84	2.24	1.29	2.15	0.32	0.72	0.51	0.11	2.35	0.06
Na_2O	7.77	5.06	6.42	8.14	8.84	4.67	4.22	2.49	0.02	0.04
K_2O	2.53	5.05	4.55	4.46	1.95	4.92	4.95	5.38	5.05	7.14
P_2O_5	0.52	0.23	0.11	0.54	0.23	0.12	0.05	0.03	0.00	0.01
H_2O	0.73	0.46	0.08	0.39	0.60	0.23	0.10*	0.47*	3.31*	1.18*
CO_2	0.00	0.30	0.00	0.09	0.12	0.07	0.03	0.08	–	–
F	0.19	0.09	0.04	0.03	0.06	0.16	0.02	0.04	–	–
F=O	-0.08	-0.04	-0.02	-0.01	-0.03	-0.07	-0.01	-0.02	–	–
Total	99.64	99.28	98.21	100.33	99.11	98.29	98.94	98.57	99.75	99.69
Zr	260	432	1890	1853	205	1087	838	868	1161	1042
Y	160	63	158	200	110	133	93	95	142	109
Nb	837	22	142	204	1487	44	40	42	73	66
Be	133	5	14	16	1210	10	8	3	10	4
U	6.0	3	5	6	4	3	7.0	9.0	–	–
Th	46	2	23	26	144	11	3	13	–	–

Notes; All oxides and F in Weight %; trace elements quoted as ppm.
* H_2O is Loss on Ignition.

Table 6. Major- and minor-element analyses of representative samples of Letitia Lake Area intrusive rocks

	LL−85028 Two Tom Syenite	LL−85031 Two Tom Syenite	LL−84075 Mann Fine Grained Syenite	LL−85023 Mann Medium Grained Syenite	LL−84131 Quartz Porphyritic Syenite	LL−85067 Letitia Lake Syenite	LL−86015 Letitia Lake Granite	LL−86019 Letitia Lake Granite	LL−86002 Shallow Lake Granite	LL−86010 Shallow Lake Granite
SiO_2	60.40	60.45	61.15	63.05	63.10	61.50	75.70	72.55	78.70	74.80
TiO_2	0.78	0.81	0.80	0.50	0.82	0.76	0.30	0.45	0.21	0.24
Al_2O_3	11.41	12.65	13.29	14.19	12.01	13.27	10.61	10.21	9.73	10.73
Fe_2O_3	8.05	6.87	6.53	2.84	4.38	8.25	1.88	2.41	1.21	1.68
FeO	3.09	2.85	1.15	4.27	5.66	0.93	1.11	3.50	1.40	2.18
MnO	0.25	0.23	0.30	0.20	0.25	0.15	0.06	0.10	0.05	0.07
MgO	0.14	0.23	0.43	0.18	0.25	0.07	0.04	0.06	0.02	0.02
CaO	1.89	1.89	1.82	1.75	1.69	1.03	0.26	0.24	0.25	0.26
Na_2O	7.61	7.63	6.80	6.53	6.49	7.72	4.19	4.88	4.01	4.02
K_2O	4.40	4.80	6.82	5.16	4.40	5.20	4.75	4.83	3.82	4.62
P_2O_5	0.18	0.20	0.09	0.09	0.13	0.06	0.02	0.02	00.0	0.02
H_2O	0.38	0.31	0.29	0.64	0.46	0.35	0.17	0.24	0.13	0.27
CO_2	0.79	0.11	0.05	0.58	0.22	0.11	0.08	0.13	0.05	0.05
F	0.05	0.06	0.08	0.03	0.09	0.01	0.02	0.13	0.01	0.10
F=O	-0.02	-0.03	-0.03	-0.01	-0.04	–	-0.01	-0.05	–	-0.04
Total	99.42	99.09	99.57	100.00	99.91	99.41	99.18	99.70	99.59	99.02
Zr	3615	1704	2044	1311	1897	1706	1334	831	725	2336
Y	187	116	274	91	250	172	152	52	141	279
Nb	117	73	387	52	102	70	69	44	72	101
Be	19	13	44	10	15	14	10	7	10	21
U	9.0	3	7	5	6	5	7	1	5	12
Th	41	14	75	14	31	18	28	5	28	45

Notes: All oxides and F in Weight %; trace elements quoted as ppm.
See Table 3 for the analytical techniques.

The mafic trachytic units are either medium- to dark-green or black in appearance, whereas the more felsic varieties are light brown. Volcanogenic sediments and weathered equivalents of the lower two units occur in the upper unit to the east of the Mann #1 showing; the present study suggests that peralkaline volcanics dominate in the upper unit north and west of the Mann # 1 showing.

The syenites that are closely related to or hosting the mineralization of the Mann type are fine- to medium-grained, massive, equigranular aegirine−riebeckite ± quartz syenites. These syenites also contain perthitic feldspar and accessory astrophyllite, fluorite, aenigmatite, titanite, apatite and magnetite. Peralkaline granites in the area have similar mineralogy except that quartz and astrophyllite are more abundant and riebeckite and aegirine are less abundant; no known mineralized zones are associated with peralkaline granites in this region. Undersaturated nepheline−eudialyte−aegirine−riebeckite-bearing syenites and related rocks host the Y mineralization in the Shallow Lake area. Representative analyses of the peralkaline intrusive rocks in the Letitia−Shallow lakes area are listed in Table 6.

Mineralization. The Nb−Be mineralization in the Letitia Lake area occurs both within peralkaline volcanic rocks overlying peralkaline syenites and as veins cutting the volcanics or syenite. Miller (1987) described the geology of the individual Nb−Be mineralized zones. The Y mineralization was only recently recognized (Miller, 1986b; Batterson and Miller, 1987), and thus little is known about this mineralization.

As discussed in Miller (1987), the Nb-Be mineralization occurs in 5 different modes:

1) banded feldspar−riebeckite volcanics (M1): occurs at the Mann #1, Two Tom and one of the Mann #2 showings; these volcanics have been assigned to the lower portions of the upper unit of the Letitia Lake Group and are trachytic in composition.

2) massive aegirine−feldspar volcanics (M2): occurs at the Mann #1, Mann #2, and Michelin showings; these volcanics belong to the upper unit and are also trachytic.

3) aegirine−feldspar veins (M3): occurs at the Mann #1, Michelin, Mann #2 and Two Tom Lake showings; these veins appear to be closely related, both mineralogically and spatially, to volcanics of mode M2 and the fine grained syenites.

Table 7. Major- and minor-element analyses of rare metal mineralization from the Letitia Lake–Shallow Lakes area

	LL–84014 Mann M1	LL–84010 Mann M2	LL–84078 Mann M3	LL–84053 Mann M4	LL–85055 Michelin M5	LL–84120 Mann #2 M2	LL–85038 Two Tom M1	85-4521 Two Tom Y	LL–85084 SW Ten Mile	72115 Red Wine Suite
SiO_2	56.55	58.20	55.30	58.85	58.35	61.95	60.00	47.95	53.60	63.60
TiO_2	0.46	1.18	0.88	0.39	0.64	0.62	0.37	0.58	0.25	0.23
Al_2O_3	8.88	10.94	8.26	12.45	12.80	12.41	12.74	3.16	9.59	17.00
Fe_2O_3	4.34	6.01	14.26	1.84	9.61	9.09	5.39	11.95	10.96	1.40
FeO	8.76	3.70	1.04	5.50	1.05	0.79	3.22	1.62	6.63	0.80
MnO	1.36	0.95	0.60	1.10	0.31	0.27	0.65	3.12	0.95	0.04
MgO	0.06	1.64	0.19	0.02	0.06	0.26	0.07	0.83	0.23	0.30
CaO	1.28	3.79	1.16	1.27	1.56	0.95	0.92	7.55	1.37	0.10
Na_2O	8.64	7.02	9.70	9.20	9.69	9.43	8.83	7.69	11.13	4.90
K_2O	1.50	3.89	2.43	0.81	3.79	2.53	8.03	2.22	1.63	11.10
P_2O_5	1.00	0.19	0.25	0.65	0.07	0.10	0.17	1.53	0.03	0.02
H_2O	1.10	0.78	0.29	0.41	–	–	–	2.22*	–	0.30*
CO_2	0.03	0.01	0.07	0.00	–	–	–	–	–	–
F	0.10	0.19	0.06	0.05	0.05	0.01	0.05	–	0.07	0.02
F=O	-0.04	-0.08	-0.03	-0.03	-0.03	–	-0.03	–	-0.03	-0.01
Total	94.02	98.41	94.46	92.51	97.95	98.41	100.41	90.42	96.41	99.80
Zr	44	236	101	41	1805	1008	37	372	891	>19000
Y	156	314	622	332	217	190	384	2347	1898	1300
Nb	9856	1712	818	2908	1086	83	1744	1599	134	310
Be	1750	380	2020	2560	122	141	830	60	34	–
U	15	14	26	24	5	6	11	187	46	–
Th	1979	216	847	1753	63	254	344	5054	66	–

Notes: All oxides and F in Weight %; trace elements quoted as ppm.
* H_20 is Loss on Ignition.
Red Wine suite analysis from Curtis and Currie (1981).

4) albite-rich felsic veins (M4): occurs at the Mann #1 and rarely at the Michelin and Two Tom Lake showings.

5) disseminated (M5): occurs at the Michelin showing.

The grades of each of these modes of mineralization vary greatly (Table 7) but the vein modes (M3 and M4) generally contain the highest grades, whereas the volcanic-hosted mineralization generally contains the largest volumes.

The SW Ten Mile Lake, Two Tom Lake and Red Wine North Y showings have not been extensively studied or sampled. Analyses of one or more grab samples from each showing are listed in Table 7. A description of each of these showings is as follows:

> Two Tom Lake: Y mineralization occurs within peralkaline syenites and volcanics but appears to be sporadic in nature; it occurs with Nb–Be mineralization in M2 volcanics but not in all outcrops.
>
> SW Ten Mile Lake: high Y values have been obtained from a fine grained aegirine-rich unit (up to 80 percent aegirine), which may be a recrystallized volcanic rock or a subvolcanic dyke; this sample contains the highest Y value obtained in the Letitia Lake area.
>
> Red Wine Alkaline Intrusive Suite: sporadic analyses with anomalously high Y values have been reported (Curtis and Currie, 1981) from various undersaturated units of this complex; unfortunately no locations have been published for these samples.

Figure 9 illustrates the relationships between the Letitia Lake Group, the peralkaline syenites, the various modes of Nb–Be mineralization and the volcanic-hosted Y mineralization. Most Nb–Be showings in the Letitia Lake area are associated with peralkaline syenite, although significant mineralization has not been discovered near all of the mapped syenites; peralkaline granites do not appear to host mineralization, although they are enriched in many of the rare metals.

Setting. The subaerial volcanic rocks and related intrusives of the Letitia Lake Group and Red Wine Alkaline Intrusive Suite have been interpreted as a rift-related sequence (Hill and Thomas, 1983). A U–Pb (zircon) date for a quartz–feldspar porphyry gave 1327 ± 14 Ma (Thomas, 1981) and a Rb–Sr wholerock isochron date of 1327 ± 75 Ma was obtained for the undersaturated Red Wine suite (Blaxland and Curtis, 1977). These dates indicate that the Red Wine suite and the Letitia Lake Group are Neohelikian in age.

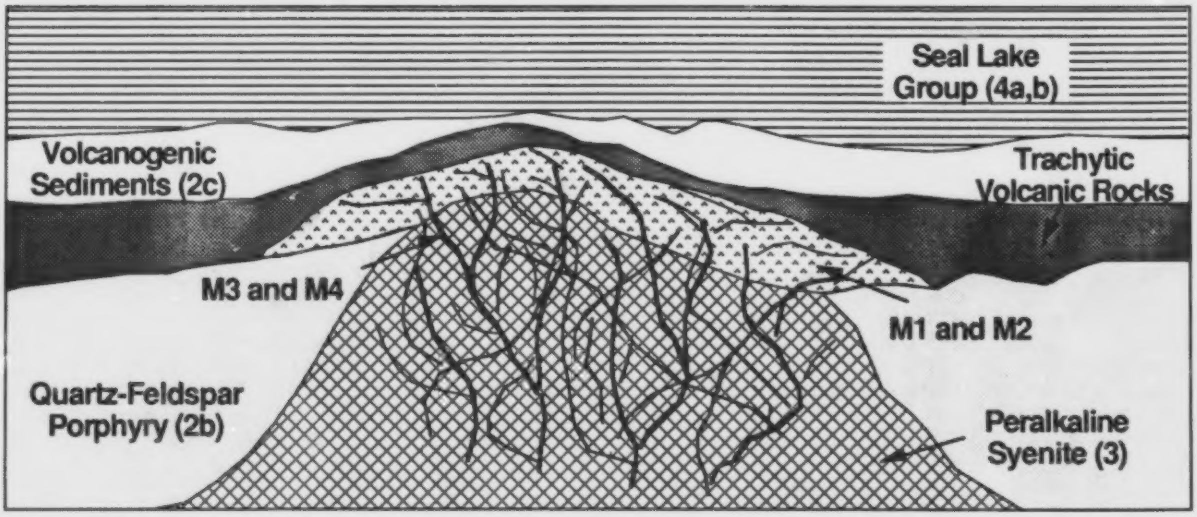


Figure 9. *Sketch illustrating the setting and types of rare-metal mineralization in the Letitia Lake area. See Figure 8 for an explanation of the numbers in brackets and see the text for a description of the mineralization types designated M1, M2, etc.*

Many of the volcanic rocks and porphyries in the lower and middle units of the Letitia Lake Group are not peralkaline with regard to major-element chemistry and mineralogy, but the trace-element comparisons of Hill and Thomas (1983) readily illustrate the peralkaline nature of all of these rocks. Subsequent analyses and thin section examination of quartz–feldspar porphyries indicate that some rocks also have peralkaline major-element chemistry and mineralogy. This adds support to the conclusion of Hill and Thomas (1983) that sodium leaching may have been responsible for the lack of peralkaline minerals and the low Na_2O contents of some of the Letitia Lake Group volcanics. The recognition of high Na_2O and aegirine–riebeckite-rich volcanics in the middle and upper units further confirms the peralkaline nature of the volcanics.

The location of most of the Nb–Be–Y showings within or near peralkaline syenite stocks and related peralkaline, trachytic to comenditic volcanic rocks indicates that this mineralization is high-level magmatic in origin and setting. Figure 9 illustrates the volcanic–subvolcanic setting. These spatial–chemical relationships indicate that the syenites represent the volcanic centres that produced the trachytic volcanics. It also appears likely that the quartz–feldspar porphyries and related comenditic–pantelleritic volcanic rocks were produced from volcanic centres located over or near the peralkaline granite stocks.

CONCLUSIONS

Mineralization Modes and Settings

The descriptions of known rare-metal deposits and showings in Labrador indicate that there are four major rock types with which rare-metal deposits in Labrador are associated:

1) peralkaline granites

2) peralkaline syenites (saturated)

3) undersaturated peralkaline intrusives

4) peralkaline trachytic and rhyolitic volcanics

All of these rock types occur at high levels within the crust as either volcanic feeder stocks, unvented plutons or volcanics.

Unvented plutons (e.g., Strange Lake) appear to have a high potential for large tonnages of rare-metal mineralization if processes within the magma chamber are able to concentrate the rare metals at or near the top of the chamber. In this setting, the mineralization would occur as pegmatite–aplite dykes, or, as late-stage medium grained intrusions at or near the top of the stock, or above the main portion of the stock in cupolas or subsidiary intrusions. Venting of part of the magma chamber to the surface would result in a wider distribution of rare metals and a reduced likelihood of their being concentrated in economic deposits.

Volcanic feeder stocks, such as those in the Letitia Lake area and the Flowers River suite, also have anomalous rare-metal contents in their higher levels. In the Letitia Lake example, the mineralization occurs in fine- to medium-grained veins, whereas at Flowers River it occurs in pegmatitic–aplitic dykes. Exploration targets in this setting would include large veins and dykes or areas with a high concentration of veins and dykes. There may also be small Strange Lake-like mineralized cupolas or subsidiary intrusions in volcanic feeder stocks, although these would be less frequent and tonnages smaller than in the unvented pluton setting.

The best exploration targets in peralkaline volcanics (e.g., the Letitia Lake area and the Flowers River suite) would be in rocks that formed from rare-metal-enriched magma that had collected at the top of the magma chamber. Presumably, as at Letitia Lake, flows or possibly thick pyroclastic units located near the vent would be the best targets for large tonnages of stratiform, rare-metal mineralization. Volcanic-hosted deposits could also provide large tonnages of lower grade material.

Rare-Metal Exploration Targets in Labrador

This compilation of data on known rare-metal deposits in Labrador reveals several poorly evaluated or unevaluated rare-metal exploration targets in Labrador. A glance at the status column in Table 2 indicates that several showings are not currently staked and that some of these showings have not been explored at all. Showings or areas that should be of particular interest to exploration companies are listed below.

Letitia Lake Area

- The Mann #2 and Michelin Nb–Be showings, which have not been adequately evaluated by surface sampling or drilling.

- The SW Ten Mile Lake showing and the immediate vicinity, which have not been previously explored for Y. The high value obtained in a grab sample from this showing indicates that there is good potential for significant Y mineralization.

- If the interpretation of Miller (1987) is accepted as a plausible model for the location of Nb–Be deposits, then several other zones within the Letitia Lake area, from which no known mineralization has been reported, are also favourable targets.

- The large peralkaline syenite–granite complex southwest of Letitia Lake may also be a good target for pegmatite–aplite or subsidiary intrusion rare-metal mineralization similar to Strange Lake.

Shallow Lake area

- The Shallow Lake peralkaline granite, which has anomalous rare-metal contents, has not been explored for rare-metal-enriched, pegmatite–aplite or subsidiary intrusion mineralization.

- The high values obtained in grab samples from undersaturated rocks of the Red Wine Alkaline Intrusive Suite and the recent discoveries, in North America, of Y in eudialyte-bearing undersaturated rocks similar to the Red Wine intrusive rocks, should make these Y occurrences very good exploration targets.

Flowers River suite

- This suite presents a large area favourable for rare-metal mineralization. Following the interpretation of Hill (1981, 1982), the roof zone of the peralkaline granite batholith would be a very favourable target for cupola or subsidiary intrusion mineralization. Analyses of some peralkaline granite outcrops, interpreted to be distant from the roof zone, indicate that nonroof zone granites are not favourable for rare metal and, in particular, Y mineralization.

- Further exploration for pegmatite–aplite dykes similar to the one sampled by Hill (1982) may also be rewarding. These are located throughout the suite but the most interesting ones probably intrude the roof zone of the granite or the overlying volcanic rocks.

- The high values for Y and some of the other rare metals in the peralkaline volcanics indicate that these rocks may also contain economically interesting showings of stratiform rare-metal mineralization. Since these volcanic rocks overly the peralkaline granite it is assumed that they are near the vent.

Other regions of peralkaline intrusive–extrusive activity

The work of Hill and Thomas (1983), in demonstrating that the Na_2O-poor volcanics of the Letitia Lake Group and the Flowers River Igneous Suite are peralkaline in nature, and the subsequent discovery of Na_2O-rich peralkaline volcanic rocks in the Letitia Lake Group indicates that the current geological mapping of Labrador need not necessarily be correct with respect to the occurrence of peralkaline volcanic rocks. Thus, other occurrences of felsic volcanic rocks should be carefully studied to determine if they are peralkaline and favourable for rare-metal exploration.

A brief review of the geochemistry and petrography of the rhyolitic flows, pyroclastics and quartz–feldspar porphyries of the Upper Aillik Group in the Central Mineral Belt of Labrador suggests that some of these rocks are peralkaline and may be good rare-metal targets. Some of the evidence for this interpretation is:

1) Analyses by Ghandi (1978) and Gower *et al.* (1982) showing many analyses of these rocks with Y in the 50 to 100 ppm range and Zr in the 400 to 1500 ppm range; many of these rocks host U mineralization.

2) Many reports indicate that aegirine and riebeckite occur in these rocks (Ghandi, 1978; Gower *et al.*, 1982; King, 1963; Minatidis, 1975; Watson-White, 1974 and Morse, 1961).

3) Analyses for Zr by Minatidis (1975) from the Michelin, Rainbow, Emben and McLean uranium

showings and deposits indicate that values up to 2200 ppm Zr are not uncommon in these areas.

4) Barua (1969) reported a crystal tuff (analysis # 31) with 65.90 percent SiO_2, 18 ppm Be, 140 ppm Y and 275 ppm Zr.

The felsic (peralkaline ?) volcanics of the Upper Aillik Group have only been extensively prospected for U, Mo and base metals whereas the rare-metal elements have received no attention.

Insular Newfoundland

Even though this report is based on data from deposits and showings in Labrador, there are a large number of similar geological settings in insular Newfoundland that have a high potential for rare-metal deposits. The models and exploration criteria outlined in this report can also be applied to insular Newfoundland (e.g., St. Lawrence peralkaline granite, Topsails intrusive suite, Louil Hills intrusive suite, King's Point complex).

ACKNOWLEDGMENTS

The field data for the Letitia Lake and Strange Lake sections of this report were gathered in the summers of 1984, 1985 and 1986. Dave Molloy, Campbell Churchill and Tony Power aptly carried out the duties of field assistant during these field seasons. Wayne Tuttle and Ken O'Quinn provided exceptional logistical support from Goose Bay for the Letitia Lake and Strange Lake field camps. Sample preparation, major element and most of the trace-element analyses of samples from the Strange Lake area and those of the author from the Letitia Lake area, were provided by Hank Wagenbauer and assistants from the Department of Mines geochemical laboratory. The manuscript was improved by comments from A. Kerr and S. Swinden.

REFERENCES

Barua, M.C.
1969: Geology of uranium–molybdenum-bearing rocks of the Aillik–Makkovic Bay area, Labrador. Unpublished M.Sc. thesis, Queen's University, Kingston, Ontario, 76 pages.

Batterson, M. and Miller, R.
1987: A new Y–Nb–Be showing in the western part of the Central Mineral Belt, Labrador. Newfoundland Department of Mines, Mineral Development Division, Open File 13L/1 (66), 5 pages.

Blaxland, A.B. and Curtis, L.W.
1977: Chronology of the Red Wine alkaline province, central Labrador. Canadian Journal of Earth Sciences, Volume 14, pages 1940-1946.

Curtis, L.W. and Currie, K.L.
1981: Geology and petrology of the Red Wine alkaline complex, central Labrador. Geological Survey of Canada, Bulletin 294, 64 pages.

Dawe, R.
1984: Mineral-based opportunities in Newfoundland and Labrador. A presentation to Japanese business representatives in Tokyo, Japan. Newfoundland Department of Mines, unpublished document.

Dujardin, R.A.
1961: Ten Mile Lake drilling report. Unpublished report for Rio Tinto Exploration Limited. [13L/1 (12)]

Duthou, J.L., Pillet, D. and Chenevoy, M.
1986: Rb–Sr geochronology of the Lac Brisson peralkaline granite (Labrador, N.E. Canada). Abstract, International Geochemica Cosmochemica Congress, Cambridge, England.

Ghandi, S.S.
1978: Geological setting and genetic aspects of uranium occurrences in the Kaipokok Bay–Big River area, Labrador. Economic Geology, Volume 73, pages 1492-1522.

Gower, C.F., Flanagan, M.J., Kerr, A. and Bailey, D.G.
1982: Geology of the Kaipokok–Big River area, Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-7, 77 pages.

Hill, J.D.
1981: Geology of the Flowers River area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-6, 40 pages.

1982: Geology of the Flowers River–Notokwanon River area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-6, 140 pages.

Hill, J.D. and Thomas, A.
1983: Correlation of two Helikian peralkaline granite–volcanic centres in central Labrador. Canadian Journal of Earth Sciences, Volume 20, pages 753-763.

Jacobson, R.R.E., MacLeod, W.N. and Black, R.
1958: Ring-complexes in the younger granite province of northern Nigeria. Memoirs of the Geological Society of London, Volume 1, 71 pages.

King, A.F.
1963: Geology of Cape Makkovik peninsula, Aillik, Labrador. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 114 pages.

Miller, R.R.
1986a: Geology of the Strange Lake Alkalic Complex and the associated Zr–Y–Nb–Be–REE mineralization. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 11-19.

1986b: Preliminary data from rock samples of the Letitia Lake area, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File 13L/63, 8 pages.

1987: The relationship between Mann-type Nb–Be mineralization and felsic peralkaline intrusives, Letitia Lake Project, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 83-91.

Minatidis, D.S.
1975: A comparative study of trace element geochemistry and mineralogy of some uranium deposits of Labrador, and evaluation of some uranium exploration techniques in glacial terrain. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 216 pages.

Morse, S.A.
1961: Petrographic notes on Aillik molybdenum showings, Labrador (N.T.S. 13O/3). British Newfoundland Exploration Ltd. Unpublished document G-61003, 4 pages. [13O/3 (47)].

Thomas, A.
1980: A summary of geology and data collected during 1978 in the Red Wine Lake-Letitia Lake area, central Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File 13L (56), 44 pages.

1981: Geology along the southwestern margin of the Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-4, 40 pages.

U.S. Bureau of Mines
1985a: Mineral Commodity Summaries.

1985b: Mineral Facts and Problems, 1985 Edition. U.S. Bureau of Mines, Bulletin 675.

1987: Mineral Commodity Summaries.

Venkatswaren, G.P.
1983: A report on the geological, geophysical and geochemical assessment work, Strange Lake area, Newfoundland-Labrador, N.T.S. Sheet 24A/8. Unpublished report, Iron Ore Company of Canada. [24A/8 (6)]

Watson-White, M.V.
1974: A petrological study of acid volcanic rocks in part of the Aillik Series, Labrador. Unpublished M.Sc. thesis, McGill University, Montreal, Quebec, 92 pages.

Note: Mineral Development Division file numbers are included in square brackets.

*Current Research (1988) Newfoundland Department of Mines
Mineral Development Division, Report 88-1, pages 247-259*

INDUSTRIAL MINERALS AND FOLLOW-UP OF LAKE- AND STREAM-SEDIMENT GEOCHEMICAL ANOMALIES IN LABRADOR

J.R. Meyer and P.L. Dean[1]
Mineral Deposits Section

ABSTRACT

During the 1987 field season, a program of industrial-mineral exploration and geochemical follow-up work was carried out in western, southeastern, and northern Labrador.

In western Labrador, Proterozoic outliers of the Sims Formation near the Esker highway were examined as potential sources of silica. A 600-m section was sampled on the Sims outlier; grab samples were obtained from three other outliers. A kyanite–garnet–mica prospect was sampled 6 km southeast of Wabush, and pegmatites containing large biotite crystals are reported from new roadcuts on the Trans-Labrador Highway.

During geochemical follow-up work in southeastern Labrador, five styles of potential mineralization with adjacent lake sediment geochemical anomalies were recognized: 1) gold in hydrothermal veins and pegmatites; 2) clastic-hosted base and precious metals in pyritic zones; 3) platinum-group-element mineralization in mafic plutonic rocks; 4) precious metals and uranium associated with late Grenvillian plutons; and 5) base and precious metals, and uranium in late Precambrian–early Paleozoic cover sequences. Industrial-mineral potential in the area includes quartz–feldspar–mica pegmatites, and zirconium-rich, mylonitic metasediments.

The industrial-mineral survey in northern Labrador concentrated on silica and dolomite evaluation within the Aphebian Ramah Group, and an assessment of a graphite deposit at the west end of Saglek Fiord. Geochemical follow-up work in the Ramah Group consisted of rock and silt sampling in the vicinity of Au, Zn, Pb, and As stream sediment anomalies. In the Saglek area, Au, W, U, As, Zn, and Pb geochemical anomalies in both stream and lake sediments were briefly examined and four potential exploration targets were identified.

INTRODUCTION

The 1987 industrial-mineral program in Labrador was the fourth year in an assessment of its industrial-mineral potential, with an emphasis on dolomite and silica resources. Initial investigation of a dolomitic marble formation in the Labrador City–Wabush area in 1984, led to the development of quarries, which supply flux used in the production of iron ore pellets by the Iron Ore Company of Canada. Surface sampling and subsequent drilling of extremely pure silica deposits 3- to 5-km west of Labrador City, has brought the area to the attention of major silica producers and consumers in Canada. A feasibility study is currently looking into the economics of establishing secondary manufacturing of silica-based products in the Labrador City area, using relatively inexpensive hydroelectric power from Churchill Falls. During the 1987 field season, one new dolomite prospect and three new silica prospects were evaluated.

Lake- and stream-sediment geochemical surveys in southeastern and northern Labrador indicate many geochemical anomalies and areas having potential for mineral discoveries (Geological Survey of Canada, 1984, 1986, 1987). However, due to the remoteness of these areas, little follow-up work has been undertaken by the mining industry. Regional and detailed geological mapping, carried out by the Newfoundland Department of Mines and the Geological Survey of Canada, are providing the geological background necessary to evaluate these geochemical anomalies. Follow-up work carried out in the 1987 field season has begun this process by identifying many potential exploration targets in southeastern and northern Labrador.

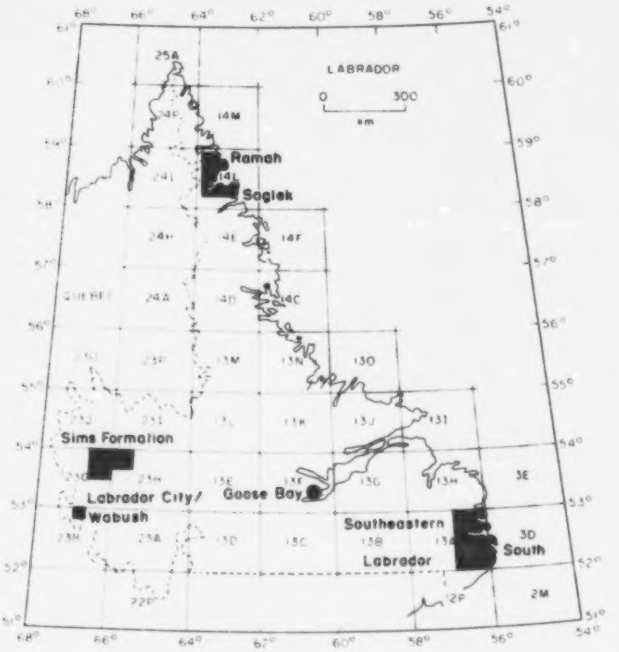
WESTERN LABRADOR

Sims Formation

In June 1987, a one-week sampling program was carried out in the Proterozoic Sims Formation in western Labrador (Figure 1), which consists of 100 m of fluvial arkose and conglomerate overlain by 600 m of predominantly marine quartz arenite (Ware and Hiscott, 1985). The Sims Formation

---

[1] Mineral Lands and Mines, Newfoundland Department of Mines



INDEX MAP

Figure 1. *Location of 1987 field areas.*

was described in an unpublished M.Sc. thesis by Ware (1983). Geochemical analyses of three samples of quartz arenite reported in his thesis indicate that this unit is very pure, containing approximately 2 percent impurities (Table 1).

Table 1. Analyses of Sims quartz arenite (Ware, 1983)

Sample Location	Fe_2O_3 %	Al_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %
Sim's outlier	0.10	1.54	0.04	0.04	0.007	0.46	--
Evening outlier	0.05	1.21	--	0.02	0.016	0.42	0.04
Muriel outlier	0.11	1.85	0.09	0.19	0.012	0.52	--

The Sims Formation is well exposed in three separate outliers 3- to 10-km north of the Esker road, and in one outlier 15 km south of the road (Figure 2). The outliers, which form hills with elevations up to 400 m above the surrounding area, were once part of an extensive blanket of clastic sediment, which was deposited unconformably on the Aphebian Knob Lake Group (Ware and Hiscott, 1985). All of the outliers are capped by the resistant quartz arenite unit. The 600-m thick quartz arenite unit was subdivided into four facies by Ware (1983), predominantly on the basis of paleocurrent data (crossbedding and ripple marks). The lower 75 to 100 m are interpreted as fluvial deposits, possibly reworked coastal sands. These are overlain by 20 m to 40 m of quartz granule and quartz pebble conglomerate, interbedded with medium- to coarse-grained sandstone. This latter facies, a beach deposit, is as an excellent marker bed. Ware (1983) subdivided quartz arenite above the conglomerate into 250 m of coastal and nearshore-marine sediments, overlain by 250 m of sediments deposited in an open-marine setting.

A complete section of the quartz arenite unit is exposed on the northwest side of the Sims outlier, where the authors chip sampled and briefly described a 500-m stratigraphic section in 3- to 10-m intervals. Despite the different facies within the quartz arenite unit, the rock itself is quite similar in appearance throughout. The quartz arenite is generally white in colour, with various shades of pink to purple and pale orange to brown. It is fine- to medium-grained and very well cemented with silica, typically breaking with a conchoidal fracture. It occurs in 30- to 150-cm-thick beds, which may show crossbedding or have bedding planes displaying ripple marks or sandwave-like forms. Impurities consist of minor hematite-stained laminations and dark-grey grains and crystals of hematite, which are often oxidized to a red or orange colour. The euhedral shape of these crystals (visible under a binocular microscope) suggest that they are secondary or diagenetic in origin. Minor pink feldspar grains are visible in the lower facies. Ware (1983) reports that in thin section sericite can be seen surrounding many grains.

A small section through the quartz arenite was also sampled from the southeast end of the Sims outlier, and grab samples were collected from the MacLean, Muriel, and Evening outliers. The pebble conglomerate was located in all but the Evening outlier and will facilitate stratigraphic correlation of the samples. Geochemical results from chip samples will give a better indication of the amount of impurities and the potential of these deposits as a source of high-purity silica. The potential availability of cheap hydroelectric power from the Churchill Falls power station, and the close proximity of these outliers to the Esker highway, which connects Churchill Falls to the Quebec North Shore and Labrador Railway, would make these deposits attractive to major silica producers if one or more of the quartz arenite facies have sufficiently low impurity levels.

Labrador City Area

Several kyanite and graphite occurrences were investigated in the Labrador City–Wabush area. The occurrence that appears to have the best potential is the Flora Lake kyanite prospect, located 400 m west of the south end of Flora Lake (Figure 3). This prospect has been described by Boyko (1953) and Rivers (1978). Crystals of blue kyanite, up to 5-cm long, occur in a garnet–mica–quartz gneiss. The prospect consists of a 30- to 50-m wide zone, within a north-trending ridge that extends along strike for at least 1 km. This zone contains up to 20 percent kyanite, 10 to 20 percent garnet (crystals up to 1.5 cm), and 10 to 15 percent mica (dominantly muscovite). All three minerals would have economic potential if they could be efficiently separated from the host rock.

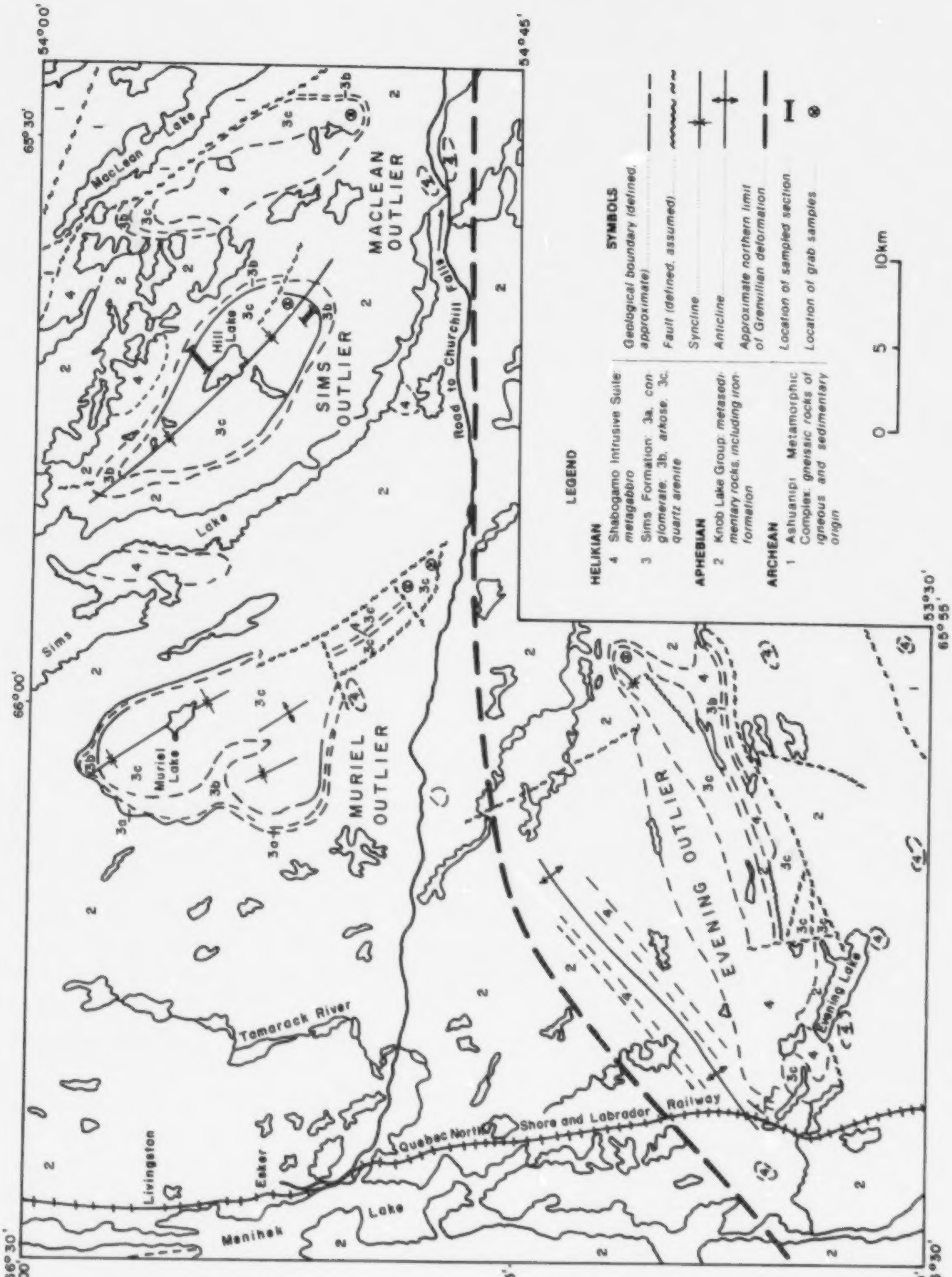

54°00'
66°30'
66°00'
65°30'
54°00'
53°45'
53°30'
66°30'
53°30'
65°55'
54°45'
Sims Lake
MacLean Lake
Hill Lake
Muriel Lake
Tamarack River
Menihek Lake
Livingston
Esker
Quebec North Shore and Labrador Railway
Road to Churchill Falls
Evening Lake
SIMS OUTLIER
MACLEAN OUTLIER
MURIEL OUTLIER
EVENING OUTLIER
LEGEND
HELIKIAN
4 Shabogamo Intrusive Suite: metagabbro
3 Sims Formation: 3a, conglomerate; 3b, arkose; 3c, quartz arenite
APHEBIAN
2 Knob Lake Group: metasedimentary rocks, including iron formation
ARCHEAN
1 Ashuanipi Metamorphic Complex: gneissic rocks of igneous and sedimentary origin
SYMBOLS
Geological boundary (defined, approximate)
Fault (defined, assumed)
Syncline
Anticline
Approximate northern limit of Grenvillian deformation
Location of sampled section
Location of grab samples
0
5
10km

Figure 2. *Geological map of the Sims Formation (after Ware and Wardle, 1979).*

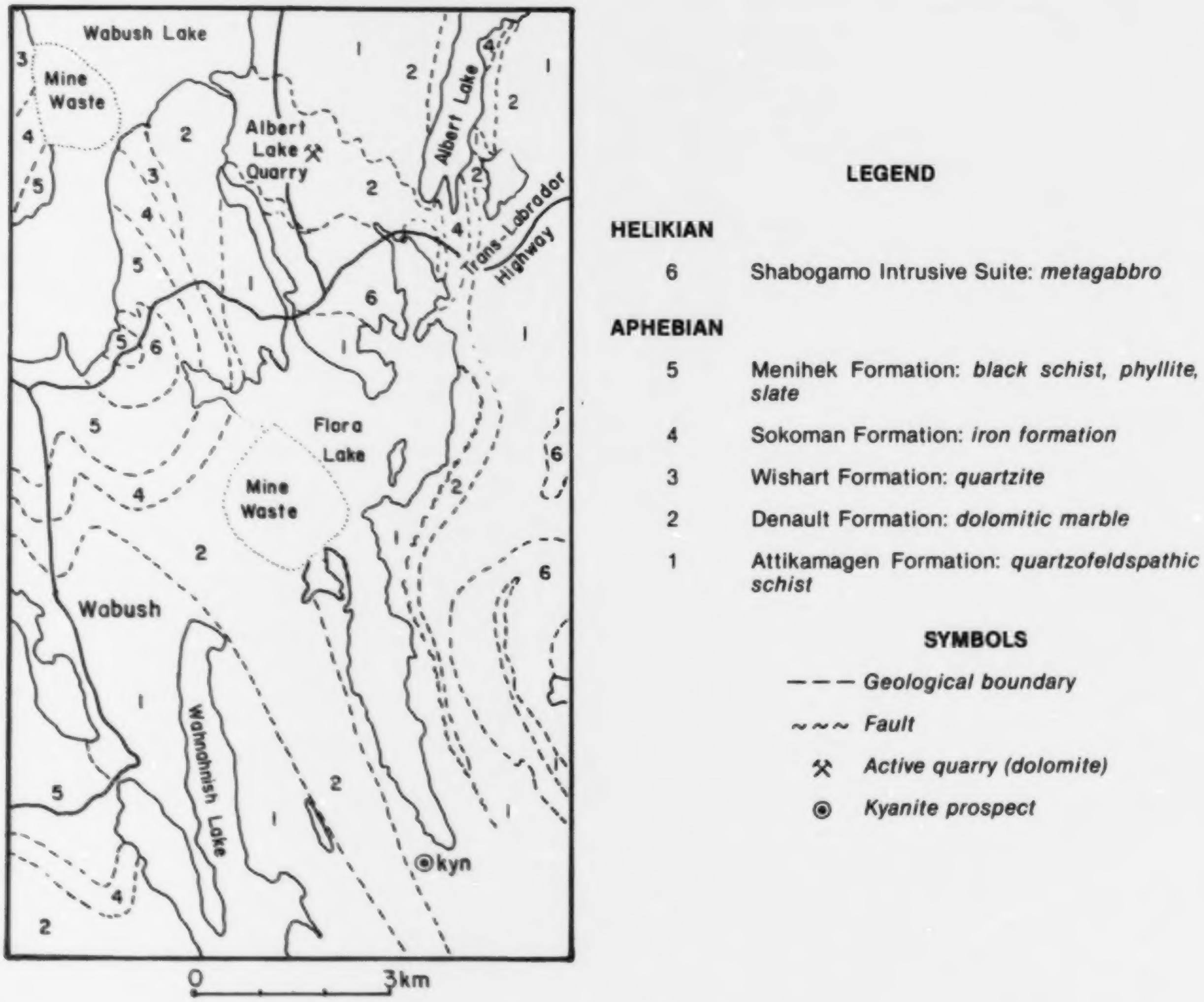

Wabush Lake
Mine Waste
Albert Lake Quarry
Albert Lake
Trans-Labrador Highway
Flora Lake
Mine Waste
Wabush
Wahnahnish Lake
kyn
0
3km
LEGEND
HELIKIAN
6 Shabogamo Intrusive Suite: metagabbro
APHEBIAN
5 Menihek Formation: black schist, phyllite, slate
4 Sokoman Formation: iron formation
3 Wishart Formation: quartzite
2 Denault Formation: dolomitic marble
1 Attikamagen Formation: quartzofeldspathic schist
SYMBOLS
Geological boundary
Fault
Active quarry (dolomite)
Kyanite prospect

Figure 3. *Geological map of the Labrador City–Wabush area.*

Road construction on the Trans-Labrador Highway, between Emeril and Twin Falls, has intersected several pegmatites. Biotite crystals in the pegmatites range in size up to 25 cm by 15 cm, and were sampled by Rod Klassen and Frank Thompson of the Geological Survey of Canada. The samples were kindly passed on to the Newfoundland Department of Mines.

SOUTHEASTERN LABRADOR

A lake sediment geochemical survey released by the Geological Survey of Canada in 1984 for southeastern Labrador (Geological Survey of Canada, 1984) indicates the presence of many multi-element anomalies near the coast where overburden is relatively thin. Using preliminary geological maps by Gower *et al.* scheduled for publication in 1988 for the Port Hope Simpson and St Lewis River map regions, geochemical follow-up (consisting of rock and silt sampling) was carried out. Several industrial-mineral prospects were also investigated during the course of this work.

The Port Hope Simpson and St Lewis River map regions are located within the Grenville Province and are divided into six northwest-trending, lithostructural entities by Gower *et al.* (1987, *this volume)* (Figure 4). Lithologies include metasedimentary gneisses, a major mafic plutonic body (White Bear Arm complex), and a variety of granitoid rocks including several late Grenvillian plutons. There are, in addition, two sets of mafic dykes that intrude the region; they are considered to be late Precambrian–early Paleozoic and late Paleozoic in age (Gower *et al.*, 1987). These late- and post-Grenvillian intrusions are often coincident with lake sediment geochemical anomalies.

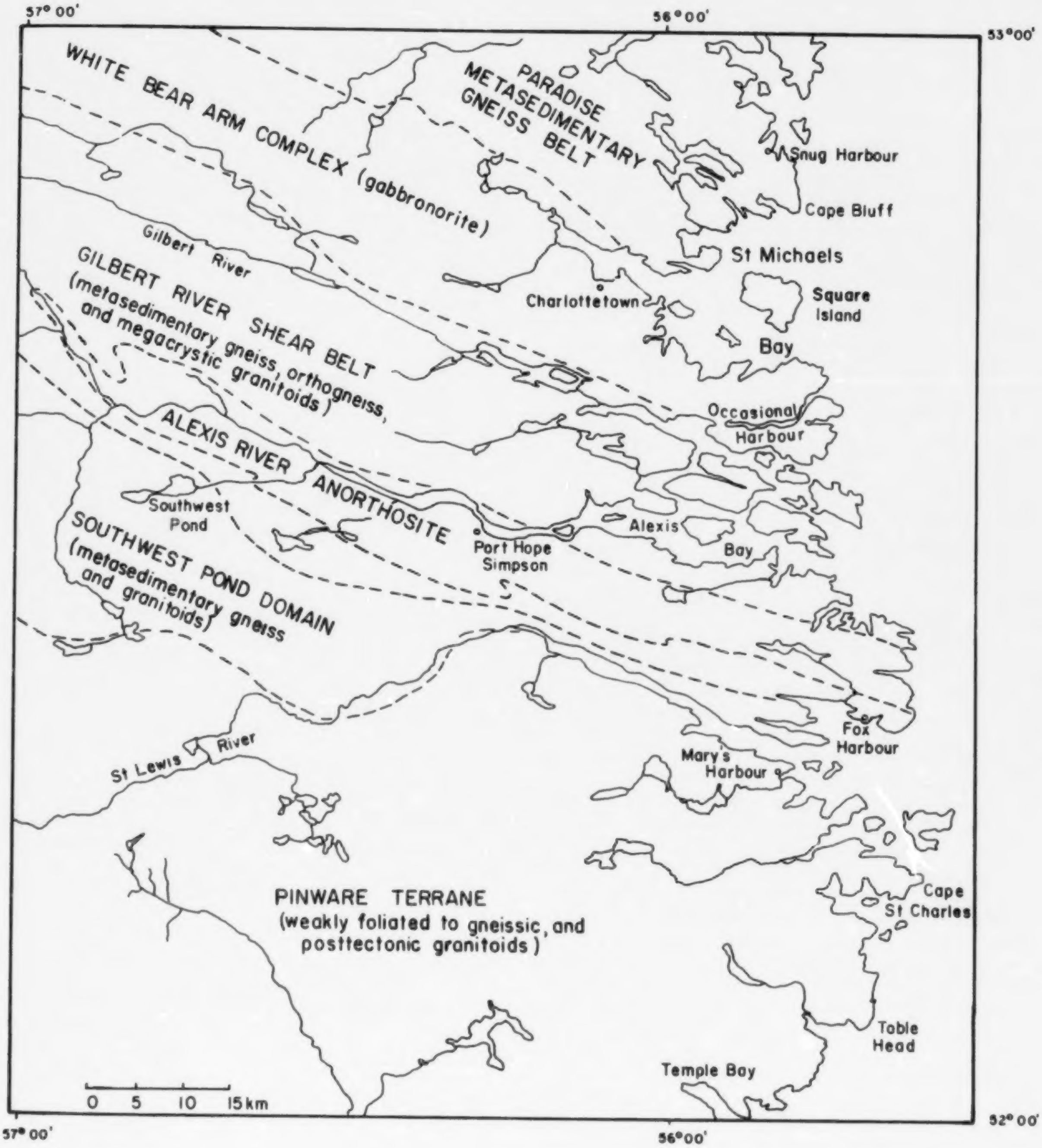

57° 00'
56° 00'
53° 00'
WHITE BEAR ARM COMPLEX (gabbronorite)
PARADISE METASEDIMENTARY GNEISS BELT
Snug Harbour
Cape Bluff
St Michaels
Square Island
Bay
Charlottetown
Gilbert River
GILBERT RIVER SHEAR BELT (metasedimentary gneiss, orthogneiss, and megacrystic granitoids)
Occasional Harbour
ALEXIS RIVER ANORTHOSITE
Southwest Pond
Port Hope Simpson
Alexis Bay
SOUTHWEST POND DOMAIN (metasedimentary gneiss and granitoids)
Fox Harbour
Mary's Harbour
St Lewis River
PINWARE TERRANE (weakly foliated to gneissic, and posttectonic granitoids)
Cape St Charles
Table Head
Temple Bay
0 5 10 15km
57° 00'
56°00'
52° 00'

Figure 4. *Lithostructural subdivisions of southeastern Labrador (after Gower* et al., *1987,* this volume).

LEGEND (Figure 5)

UPPER PROTEROZOIC–LOWER CAMBRIAN

9	*gabbro, olivine gabbro*

MIDDLE PROTEROZOIC

8	*gabbro, norite, troctolite*
7	*monzonite, monzodiorite, and syenite*
6	*leucogabbro and leuconorite*
5	*amphibolite and retrograded metagabbro*

MIDDLE OR LOWER PROTEROZOIC

4	*amphibolite*
3	*sillimanite-bearing, quartz–feldspar schist and gneiss*
2	*biotite–hornblende diorite gneiss*
1	*biotite granite gneiss*

SYMBOLS

— — —	*Geological boundary*
~~	*Fault*
⊥⊥⊥	*Pyritic zones*
o	*Lake sediment geochemical anomalies*

Ag .... Silver
As .... Arsenic
Cd .... Cadmium
Cu .... Copper
Hg .... Mercury
Mo .... Molybdenum
Ni .... Nickel
U .... Uranium
Zn .... Zinc

Geochemical Follow-up

Geochemical follow-up work will be discussed in 6 parts, categorized on the basis of lithological and geographical associations.

Hydrothermal veins and pegmatites. The St. Michaels Bay area, in the Port Hope Simpson map region, is cut by a major north-northeast-trending mafic dyke and many quartz–potassium feldspar–biotite pegmatites (Figure 5). In the northwest corner of this area, on the west side of New York Bay, there is an As–Cd–Mo–Ag–Hg–Cu lake sediment anomaly. A zone of intense potassic alteration containing associated quartz carbonate veining and hydrothermal brecciation, was sampled from shoreline exposures adjacent to this anomaly. The quartz veins are up to 50 cm in width and commonly contain angular fragments of pervasively altered wall rock with up to 2 percent pyrite and chalcopyrite. The veins also include elongate fragments of cryptocrystalline quartz, commonly laminated, that are light to dark grey-green. Networks of thin, crosscutting quartz veins are common in the red, potassic-altered country rock. The most intense alteration and veining was seen along the shoreline, over a strike length of approximately 500 m. Two other zones of potassic alteration, with associated quartz–potassium feldspar pegmatites occur along strike 2 km to the north and 1 km to the south. Grab samples analyzed from the veins and altered country rock do not contain any anomalous gold values. Samples of coarse potassium feldspar from the pegmatite at the southern extension of the system will be dated by the K–Ar method.

Pyritic Zones. Yellow and brown, extensively weathered, limonitic and sulphur-stained outcrops are common in the Dead Islands area, in the northern part of St. Michaels Bay. The outcrops are the surface expression of pyritic zones associated with pelitic gneiss, mafic supracrustal rocks, calc-silicate layers and quartzite or metamorphic banded chert (Gower *et al.*, 1987). Pyritic zones have also been mapped inland to the west of the Dead Islands, south of Occasional Harbour, and north of Port Hope Simpson by Gower *et al.* (1987). Lake sediment geochemical results from the areas adjacent to these pyritic zones are characterized by Ag–Hg–Cu–Zn anomalies. Gold values reported from these zones by Gower *et al.* (1987) range up to 36 ppb. In several of the less weathered shoreline exposures (for example, opposite Woody Island on the south side of Lackaname Ridge), the lithologies consist of coarse grained quartzite, in beds 1 to 5-cm thick, separated by 1- to 10-mm-thick laminations of medium grained quartz–biotite–muscovite ± garnet and hornblende schist. These rocks contain 2 to 5 percent pyrrhotite–pyrite ± chalcopyrite. Preliminary geochemical results indicate that the samples contain up to 42 ppb Au, 210 to 440 ppm Zn, and up to 18 ppm As and 64 ppm Ni. If the thin quartzite beds were originally deposited as chert horizons, a possibility put forth by Gower *et al.* (1987), a compelling analogy could be drawn with Middle Ordovician cherts and shales in central Newfoundland, which are known to contain thin beds of massive banded sulphides. The association with supracrustal amphibolites, which may indicate contemporaneous volcanic activity, would suggest potential for sediment-hosted, submarine, exhalative, base-metal deposits in these metasedimentary rocks.

Mafic plutonic rocks. In the southeastern part of St Michaels Bay, two Ni–As–Mo ± U ± Cd lake sediment geochemical anomalies occur on Birchy Narrows Island, within the White Bear Arm complex, a major southwest-trending mafic plutonic body with an average width of 15 km (Gower *et al.*, 1987). The island is predominantly underlain by gabbro, norite, and troctolite. Primary igneous mineralogies and textures are visible in much of this complex

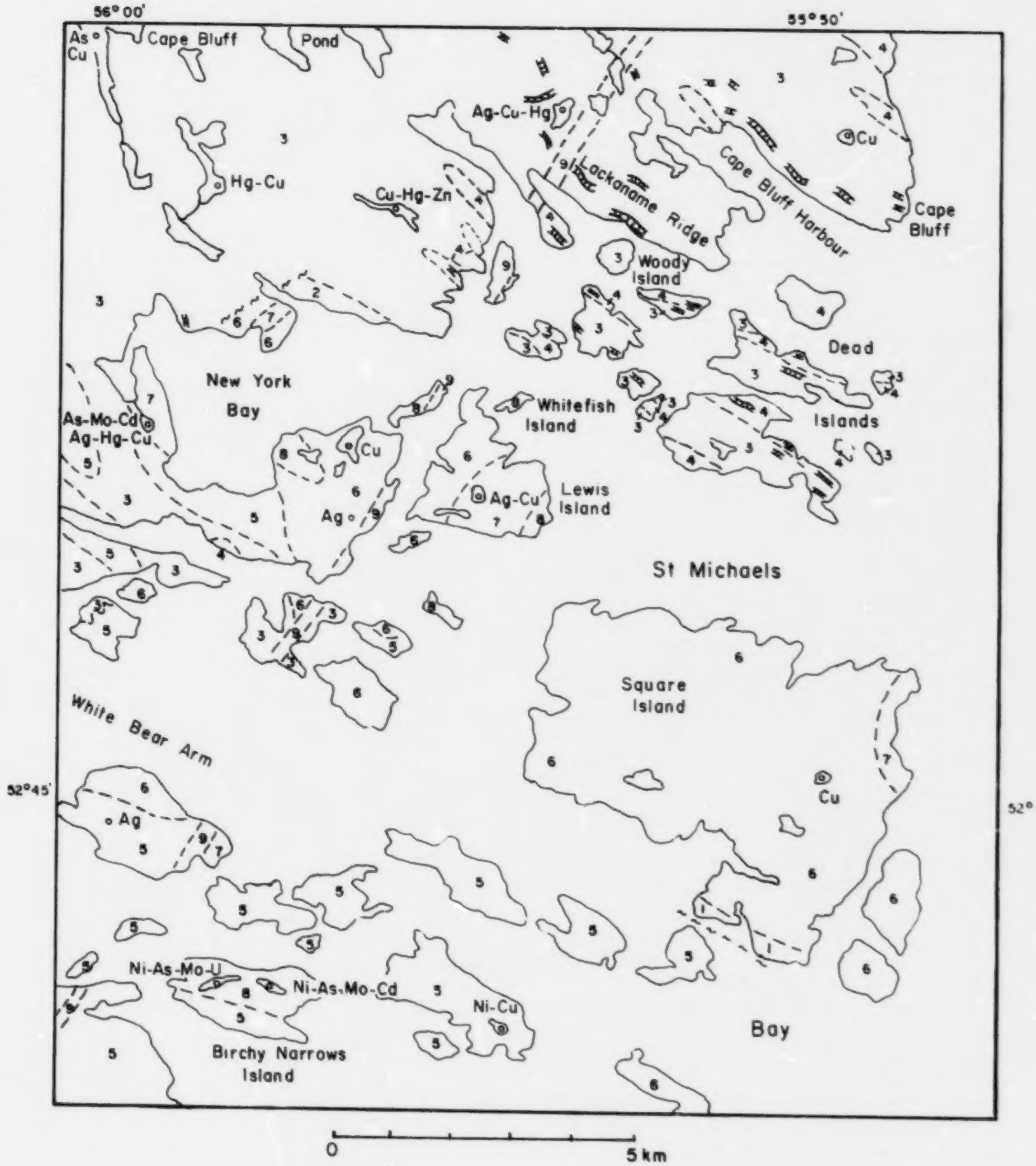

56° 00'
55° 50'
52° 45'
52° 45'
As
Cu
Cape Bluff
Pond
Ag-Cu-Hg
Hg-Cu
Cu-Hg-Zn
Cu
Lackaname Ridge
Cape Bluff Harbour
Cape Bluff
Woody Island
Dead Islands
New York Bay
As-Mo-Cd
Ag-Hg-Cu
Whitefish Island
Cu
Ag
Ag-Cu
Lewis Island
St Michaels Bay
Square Island
Cu
White Bear Arm
Ag
Ni-As-Mo-U
Ni-As-Mo-Cd
Ni-Cu
Birchy Narrows Island
0
5 km

Figure 5. *Geology of the St. Michaels Bay area, Port Hope Simpson map region (after Gower,* et al., *1987).*

and primary layering is evident in some of the more extreme compositions (Gower *et al.*, 1987). The platinum potential of the White Bear Arm complex is noted by Gower *et al.* (1987), and discussed by Wardle (1987).

On the north side of Birchy Narrows Island, intensely metamorphosed pyroxenites were sampled from a 2-m wide, vertical layer that outcrops at the shoreline. The rock is predominantly composed of clinopyroxene, hornblende, and lesser interstitial plagioclase containing well-developed garnet coronas, and opaques. Samples from this exposure are presently being analyzed for platinum-group-element mineralization.

Late Grenvillian plutons. Two late Grenvillian plutons have been mapped in the Port Hope Simpson map region by Gower *et al.* (1987). One of these plutons, the Southwest Pond granite, has adjacent Ag–Cu–Hg–U lake sediment anomalies. The granite is pink to buff-weathering and medium to coarse grained. Associated intrusions of microgranite and pegmatitic dykes are present in the surrounding country rock. The mineralogy consists of sericitized plagioclase, microcline, quartz, chloritized biotite, and accessory titanite, apatite, magnetite, and zircon (Gower *et al.*, 1987). Rock samples were collected from across the granite, from rusty zones within the country rock and red hematite-stained pegmatites. Scintillometer readings over the granite range from 280 to 540 total counts per second (tcps).

Uranium in granitic gneiss of unknown age. A large uranium lake sediment anomaly occurs adjacent to outcrops of granitic gneiss with background scintillometer readings between 950 and 1000 tcps, approximately 55 km northwest of Port Hope Simpson. The high readings are restricted to narrow zones, 5- to 40-cm wide, of plagioclase–potassium feldspar–quartz–hornblende pegmatitic and foliated granite. Adjacent zones of amphibolite have considerably lower readings. This uranium anomaly occurs 25 km northwest of the Southwest Pond granite and does not appear to be related to late Grenvillian plutons.

Late Precambrian–early Paleozoic cover sequence. Several outliers of the upper Precambrian Bateau Formation outcrop inland from Table Head, in the southeastern portion of the St Lewis River map region (Figure 4). There are several Ag–Hg–U–Pb lake sediment geochemical anomalies in the vicinity of, and possibly relating to, these outliers. A stratigraphic section through the Bateau Formation and the overlying Lighthouse Cove Formation was mapped and chip sampled to determine if local enrichment of these and other elements occur within these formations.

A 15-m section was sampled at 3-m intervals, on the southeastern side of a large outlier between Table Head and Pleasure Harbour Pond. The section consists of red to maroon, medium- to thick-bedded arkosic sandstone and conglomerate. The sandstone is colour laminated and banded, commonly crossbedded, and contains heavy-mineral laminae that consist predominantly of specular hematite. A coarse conglomerate, with 1- to 3-cm angular clasts, is exposed at the top of the section, and contains up to 5 percent magnetite. A 4-m section was also sampled through the overlying Lighthouse Cove Formation. The fine grained, amygdaloidal basalts are columnar jointed, and form the top of the outlier. Disseminated chalcopyrite was observed in several of the chip samples. A more complete description of these two formations is given by Gower *et al.* *(this volume).*

A 4-m wide, southeast-trending quartz–feldspar pegmatite, which intrudes the Grenvillian basement, but not the overlying formations, was sampled about 25 m immediately northwest of this outlier. No mineralization was observed, but scintillometer readings were 200 tcps as compared to 100 tcps over the other sampled intervals.

Industrial Minerals

Several of the large pegmatites in the St. Michaels Bay area were examined as potential sources of high-purity silica, feldspar, and mica. On Whitefish Island, immediately north of Lewis Island (Figure 5), two large pegmatites were chip sampled and described. A 3- to 5-m wide, steeply inclined pegmatite, is exposed on the southeastern side of Whitefish Island and consists of potassium feldspar, quartz and mica. Pink feldspar constitutes approximately 85 percent of the pegmatite and is coarsely crystalline; some crystals are up to 25 cm in diameter. Quartz occurs as small irregular lenses up to 60 cm in length, but typically forms graphic intergrowths with the feldspar. Biotite constitutes less than 5 percent of the pegmatite, and occurs in thin books of crystals up to 40 cm in diameter.

On the northwest side of the island, a 6- to 8-m wide, quartz–feldspar pegmatite is exposed over a strike length of 30 m. The pegmatite is well zoned, containing pods of white quartz up to 4-m wide and 15 m in length, enveloped by thinner zones of pure feldspar and graphically intergrown quartz and feldspar. There are no visible iron-bearing minerals within the quartz pods and only traces of feldspar. Chip samples were taken to assess its potential as a source of high-purity silica. If samples have less than 0.5 percent total impurities, further testing will be carried out to examine its potential for optical-grade silica.

During the investigation of a Pb–Cd–W–Cu lake sediment geochemical anomaly in Fox Harbour Pond, several lithogeochemical samples were collected from the top of a cliff 2.5 km east of Fox Harbour (Figure 4). A pale, orange-brown to purplish-brown, fine- to medium-grained mylonite was noted to have anomalous radioactivity of 800 to 1000 tcps. The mineralogy consists of quartz, plagioclase, potassium, feldspar, amphibole, and 2 to 4 percent magnetite. An initial geochemical assay returned a value of 3.4 percent Zr with anomolously high values for Ce, Hf, La, Rb, Th, Sn, Yb, and U. Comparison with peralkaline granites from Strange Lake (Miller, 1986) show Na, Ce and especially La contents to be too low for this mylonitic sample to have such a protolith. With only regional, 1:100,000-scale geological mapping having been carried out to date, the extent of these rocks is poorly known.

NORTHERN LABRADOR

Ramah Group

Introduction. During the 1987 field season, a dolomite unit and a chert unit within the Aphebian Ramah Group (Figure 6) were mapped and chip sampled. A pyrite unit and pyritic black shales directly underlying the chert unit were also sampled to determine if there are zones of base- and/or precious-metal enrichment.

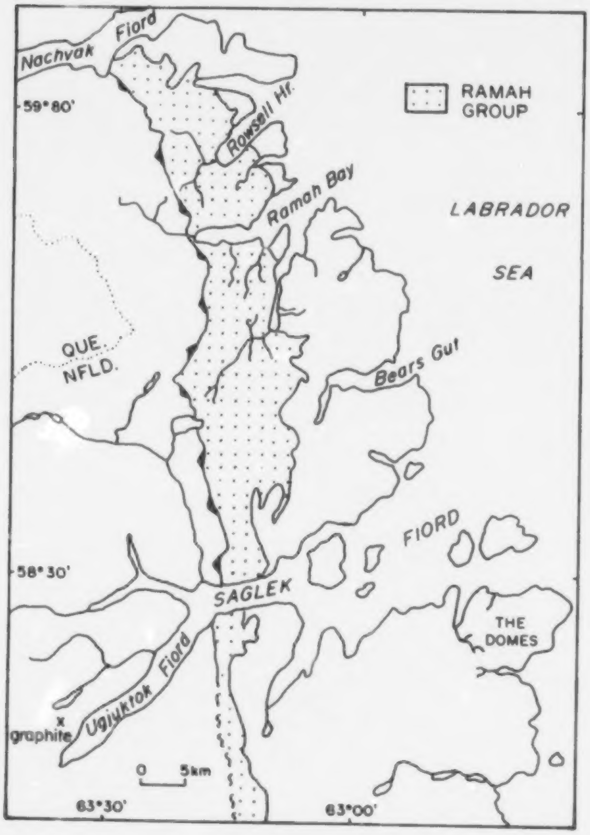


Figure 6. *Location map of Ramah Group (after Knight and Morgan, 1976).*

A regional geochemical sampling survey carried out in northern Labrador by the Geological Survey of Canada (1987), indicates Zn, Au, Pb, and Sb anomalies in streams draining the uplands underlain by the Ramah Group, and Au, W, and Pb anomalies in streams draining areas underlain by the Archean basement. Geochemical follow-up work was carried out to investigate these anomalies.

Geology. The Ramah Group comprises a 1700-m sequence of clastic and carbonate rocks deposited unconformably on Archean basement (Knight and Morgan, 1976). A lower shallow-marine, shelf sequence of sandstone, siltstone, shale and one thin volcanic flow, is capped by a thin dolomite unit. It is overlain by a thick succession of black and multicoloured shales (including pyrite and chert units), greywacke, dolomitic breccias, and thin-bedded and sandy carbonates (Knight and Morgan, 1981).

Dolomite. At the top of the shallow-marine, shelf sequence, within the Reddick Bight Formation, there is a conspicuous 3- to 10-m thick, yellow to yellow-brown weathering replacement dolomite unit, (Morgan, 1975; Knight and Morgan, 1981). Two sections of the dolomite were mapped and chip sampled at 1-m intervals.

A 5-m thick unit of massive recrystallized dolomite was sampled at the shoreline on the north side of Ramah Bay (Figure 7). The dolomite is thin- to medium-bedded and light- to dark-grey on a fresh surface. Quartz- and carbonate-veining are common. Several thin dolomite beds contain 1 to 2 percent disseminated pyrite. A 25-m section of dolomite, which may be structurally repeated, was also sampled along Warspite Brook, approximately 500 m inland from the head of Reddick Bight. At Reddick Bight, the dolomite is underlain by iron-stained dolomitic shale and sandstone, and is overlain by laminated, green to black siltstone and sandstone of the Nullataktok Formation. The yellow-weathering dolomite is light- to dark-grey banded, and finely crystalline. It is thin bedded to massive, and chert interbeds and lenses up to 65 cm thick are common and locally associated with thin shale laminations. Quartz- and carbonate-veining is ubiquitous. At the top of the section there is a thin breccia unit containing fragments of dolomitic sandstone and chert.

Pyrite and chert. Above the basal, sandy-shelf sequence, rocks of the Nullataktok Formation record an abrupt change to deep water, anoxic basinal shales (Knight and Morgan, 1981). The Nullataktok Formation consists of approximately 600 m of black and multicoloured shale and mudstone, thin-bedded silty dolomite, dolomitic breccias, pyrite, iron-formation and sedimentary chert (Knight and Morgan, 1981).

The pyrite and chert units occur near the base of the Nullataktok Formation, and vary in combined thickness from 8 to 20 m, with the chert always overlying the pyrite. The pyrite bed has attracted prospectors since the begining of the century, and several test pits were excavated. Geochemical analyses reported by Douglas (1953) from Rowsell Harbour, indicate no Cu and Au, a trace of Ag, and sulphur and iron contents that average 43 percent and 39 percent, respectively. The pyrite bed is approximately 2-m thick in Rowsell Harbour, where it consists of finely laminated pyrite, and cherty to graphitic pyrite. Two kilometers south of Little Ramah Bay the pyrite bed, which is up to 3-m thick, is laminated to pebbly. The clasts include pyrite, chert, and shale up to 10 cm in length, but averaging 1 cm. Minor chalcopyrite was observed within the brecciated beds. The pyrite unit on the north shore of Ramah Bay is 2- to 4-m thick and laminated, with secondary brecciation that produced large fragments of laminated pyrite crudely aligned parallel to bedding. Underlying the pyritic beds at Ramah Bay, there is a minimun of 40 m of yellow sulphur-stained, black, graphitic and very pyritic shale. This section was chip sampled at 3-m intervals to ascertain if there is base-metal enrichment within these beds.

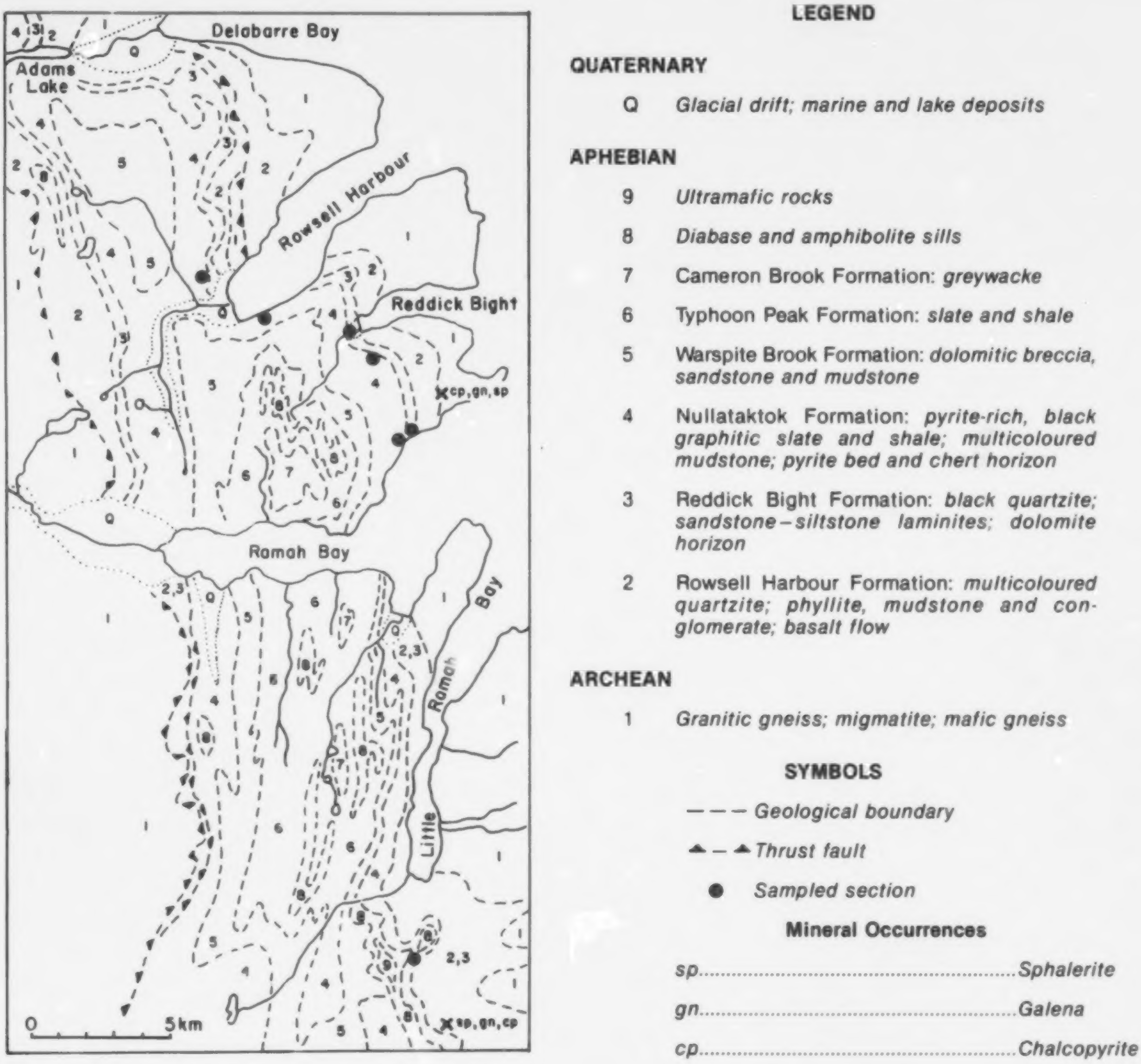

Delabarre Bay
Adams Lake
Rowsell Harbour
Reddick Bight
Ramah Bay
Little Ramah Bay
cp,gn,sp
sp,gn,cp
0
5km
LEGEND
QUATERNARY
Q Glacial drift; marine and lake deposits
APHEBIAN
9 Ultramafic rocks
8 Diabase and amphibolite sills
7 Cameron Brook Formation: greywacke
6 Typhoon Peak Formation: slate and shale
5 Warspite Brook Formation: dolomitic breccia, sandstone and mudstone
4 Nullataktok Formation: pyrite-rich, black graphitic slate and shale; multicoloured mudstone; pyrite bed and chert horizon
3 Reddick Bight Formation: black quartzite; sandstone–siltstone laminites; dolomite horizon
2 Rowsell Harbour Formation: multicoloured quartzite; phyllite, mudstone and conglomerate; basalt flow
ARCHEAN
1 Granitic gneiss; migmatite; mafic gneiss
SYMBOLS
Geological boundary
Thrust fault
Sampled section
Mineral Occurrences
sp Sphalerite
gn Galena
cp Chalcopyrite

Figure 7. *Location of sections sampled.*

Directly overlying the pyritic unit is a thick chert unit. The chert, which has been well studied by archaeologists (Fitzhugh, 1972, and Lazenby, 1980), is a source of prehistoric tools (lithics) which were extensively traded on the Labrador coast, and as far south as Maine. Exploration was also carried out by British Newfoundland Exploration Limited (BRINEX, now BRINCO) in 1959, when they evaluated the chert as a source of honing material (Grimley, 1959). In this present study, the chert is being evaluated as a source of high-purity silica. Stratigraphic mapping and chip sampling were carried out at four sections. Grab samples were collected from the whitest beds and also from three other sections that were not measured.

The chert unit ranges in thickness from 3 to a maximum of 17 m (Knight and Morgan, 1981). The thickest sections contain the highest percentage of dolomitic and shale interbeds. The chert beds have a blocky fracture and are usually heavily iron stained. This resistent unit juts out conspicuously from hillside exposures of the recessive black shales of the Nullataktok Formation.

The chert is thin to thick bedded (maximum thickness approximately 1 m), and the beds pinch and swell along strike. At the base of each section, directly above the pyrite bed, the chert is typically dark grey to black and often pyritic. The black colour is due to the presence of intercrystalline graphite

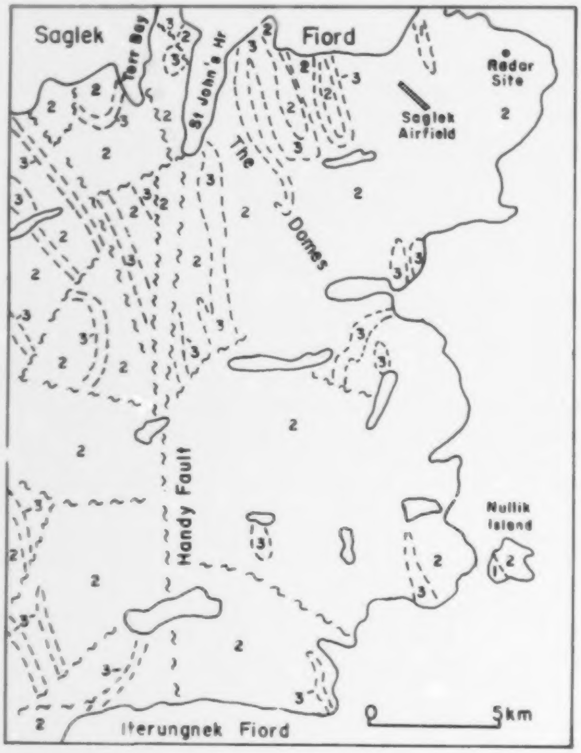
(Lazenby, 1980), and is usually associated with 1 to 5 percent pyrite. In most sections the chert is grey, but varies from white to black. The white chert rarely attains a thickness greater than 25 cm. Dolomitic beds, lenses, and nodules, and pyritic shale laminations are present in all sections, and are regularly interbedded with thin- to medium-bedded chert in the thicker sections, (i.e., on the northwest side of Rowsell Harbour). Total impurities for each section range from less than 1 percent to 20 percent, and average approximately 7.5 percent.

Geochemical Follow-Up

Area between Saglek and Nachvak fiords. A release of stream sediment geochemical data (Geological Survey of Canada, 1987) identified many multi-element anomalies, including several Au−As−Sb ± Zn ± Pb anomalies in streams draining areas underlain by the Ramah Group between Saglek and Nachvak fiords. In addition to these multi-element anomalies, there are several Zn, Pb, and As anomalies (Geological Survey of Canada, 1987). In the region to the east, which is underlain by Archean basement, there are Au, W, Pb, U, and Ni stream sediment anomalies. Rusty-weathering shales are very common in the Nullataktok and Typhoon Peak formations, especially where they are intruded by diabase sills. Both the shales and the diabase sills contain sulphides; these units were extensively sampled in places that are coincident with Au and Zn anomalies. Several other anomalies appear to coincide with previously reported mineralization (Morgan, 1975), including sphalerite within the dolomite unit of the Reddick Bight Formation south of Little Ramah Bay, and galena veins within Archean rocks north of Ramah Bay. Ultramafic rocks south of Little Ramah Bay were also sampled for Au and platinum-group-element mineralization.

Saglek area. Lake sediment and stream sediment sampling in northern Labrador has identified numerous geochemical anomalies in the Saglek area (Geological Survey of Canada, 1986, 1987). These include two adjacent As−Ni−U−Pb−Mo−Sb−W lake sediment anomalies at the north end of The Domes, several Hg−U−Ni−As−Cu−Zn−Pb−Cd−Au ± Ag anomalies in streams draining the eastern portion of the area, and the highest stream sediment Au anomaly in northern Labrador, which occurs on the west side of Torr Bay, along the northern border of the area (Figure 8).

The Saglek area is underlain by an Archean block containing some of the oldest known rocks in the Canadian Shield. The Uivak gneisses, highly deformed quartzofeldspathic gneisses, underlie approximately 50 percent of the area. Within these gneisses are rafts and belts of older rocks of the Nulliak assemblage, which include mafic and ultramafic rocks, magnetite iron-formation, calc-silicate rock and pelitic gneiss (Ryan *et al.*, 1983). The Upernavik supracrustals, which are assumed to have been deposited on, and subsequently structurally interwoven with the Uivak gneisses, consist of metasedimentary rocks interlayered with amphibolites, ultramafic pods and layered basic bodies (Bridgwater *et al.*, 1975). A major metamorphic event around 2.8 Ga produced northerly trending folds and was accompanied by the intrusion of granite sheets. A later period of igneous activity is signified by the intrusion of pale-grey, granitic sheets along shear belts (Bridgwater *et al.*, 1975). A major north-south trending fault (the Handy Fault, Bridgwater *et al.*, 1975) which cuts through St. John's Harbour, separates the area into two metamorphic domains, amphibolite-facies rocks to the east, and granulite-facies rocks to the west.



LEGEND

ARCHEAN

3 Upernavik Supracrustals: *metasedimentary rocks, metavolcanic and mafic/ultramafic intrusive rocks*

2 Quartzofeldspathic gneiss: *Uivak gneiss and its reworked and migmatized derivatives*

1 Nulliak Assemblage: *metasedimentary and mafic−ultramafic rocks*

SYMBOLS

---- *Geological boundary*

~~~ *Fault*

Figure 8. *Geology of Saglek area.*

Four potential targets for exploration have been identified in the Saglek area. First, tungsten stream sediment
~~~

geochemical anomalies are present throughout the area, particularly the eastern portion. By analogy with similar rocks in Greenland (Appel, 1986, 1987), it is possible that the Upernavik supracrustals in this area are host to scheelite mineralization. In western Greenland, stratabound scheelite mineralization is present in the Malene supracrustals, which are equivalent to the Upernavik supracrustals in this area. The scheelite occurs as disseminated grains in amphibolite, which are often aligned in bands paralleling the unit. The scheelite is also present in veinlets, joint coatings and within calc-silicate bands within the amphibolites (Appel, 1987). A large concession area in Greenland which contains many of these occurences, is presently being explored by Kidd Creek Mines Limited (Appel, 1986).

Second, a pale-grey, granitic sheet, which outcrops to the east of St. John's Harbour (Figure 8), was found by the authors to have anomolously high radioactivity, in the range of 8,500 to 9,000 tcps. This 3-m wide unit is adjacent to a major lake sediment uranium anomaly, one of many such anomalies that exist in the eastern portion of the area. Rock samples also return anomalously high values in Pb and Mo.

Third, the highest recorded gold anomaly in stream sediments in northern Labrador occurs on the western side of Torr Bay. The stream that contains the anomaly drains an area underlain by Uivak gneisses containing abundant enclaves of the Nulliak assemblage. The latter outcrops in the stream (Ryan, personal communication, 1988). Mappable units of iron-formation and grey metachert of the Nulliak assemblage are common along the western side of the Handy Fault, 3 to 5 km south of St. John's Harbour, and are near a Au anomaly. These chemical sediments may represent a source for the gold and merit detailed exploration.

Finally, an orange-brown-weathering fault gouge is present on the steep banks of a river 3.5 km south of Torr Bay. This anomolously fresh-looking fault gouge has limonitic and hematitic (potassic ?) staining. The Handy Fault, which runs parallel to and less than 1 km west of this fault, has been possibly reactivated in Paleozoic times (Bridgwater, personal communication, 1987). This major fault could have been a locus for mineralizing fluids, in the manner postulated for major lineaments that are being explored for gold on the island of Newfoundland.

Graphite

Graphite was briefly mined at the western end of Saglek Fiord in 1942 (Carr, 1958). The deposit was first reported by H. J. MacLean who visited the site in 1940 (*in* Douglas, 1953). The site was also visited and described by Carr (1958), who examined the deposit in 1942. The deposit is located approximately 5 km north-northeast of the southwest end of Ugjuktok Fiord, at an elevation of approximately 760 m. The site is accessible by a northeast-trending valley that slopes gently down to the fiord, where a boat landing can be made at the mouth of the 'Noch-tish-swock' River (Carr, 1958). Tractor marks are still visible along the route that was used during the 1942 mining venture.

The deposit consists of a 30- to 90-cm-thick lens of coarse flake- to finely crystalline-graphite. The lense occurs within a mylonitic quartz–feldspar–garnet gneiss and is parallel to the gneissic foliation. The graphite is remarkably free of impurities over the present 8-m-long exposure and a small stockpile of graphite boulders at the base of the slope are equally pure. The deposit is exposed partway up a moderately steep dipslope, and it is 30 to 90 cm below the suface. Carr (1958) estimated that there are 20 tonnes of graphite in place and stated (page 74) that there is a good chance of 'finding larger more important deposits in this area'. MacLean (*in* Douglas, 1953) reported that four different graphite horizons are visible about 'halfway up the eastern slope', which may refer to the northwest side of Ugjuktok Fiord. Several large graphite boulders were collected from this deposit. These will be analyzed to determine the percentage of the more valuable coarse flake graphite.

Numerous occurrences of graphite are reported between Saglek and Nachvak fiords, within the mylonite unit (Coleman, 1921). Two occurences, which were briefly visited along the north shore of Nachvak Fiord and Nachvak Lake, consisted of minor disseminated graphite within the quartz–feldspar–garnet mylonite.

ACKNOWLEDGMENTS

Mike Muggridge provided excellent field assistance and great company throughout the 1987 field season. Additional field assistance was provided by S. Dunsworth in the final weeks of the summer. Charlie Gower *et al.* are thanked for their excellent hospitality and help in Port Hope Simpson, the Webb Family for their hospitality in Nain, and Winston White for the use of his cabin in Kauk Harbour. Many exciting flights up north were provided by Normand Denis of Lab Air and Larry Labadio and Roger Caissie supplied excellent helicopter support. Wayne Tuttle and Ken O'Quinn are thanked for all their help in Goose Bay and the extra special expediting services. This manuscript was reviewed and considerably improved by Ambrose Howse, Charlie Gower, Bruce Ryan and Ian Knight.

REFERENCES

Appel, P.W.U.
1986: Tungsten exploration in the southern part of the Godthab area, West Greenland. *In* Report of Activities. The Geological Survey of Greenland, Report No. 130, pages 57-60.

1987: Scheelite occurences in granulite facies metamorphosed supracrustals, West Greenland. *In* Report of Activities, 1986. The Geological Survey of Greenland, Report No. 135, pages 42-45.

Boyko, W. P.
1953: Report on the Wabush Lake Area, Labrador. NALCO Unpublished report, 6 pages. [Lab.(668)]

Bridgwater, D., Collerson, K.D., Hurst, R.W. and Jesseau, C.W.
1975: Field characters of the early Precambrian rocks from Saglek, coast of Labrador. *In* Report of Activities, Part A. Geological Survey of Canada, Paper 75-1A, pages 287-296.

Carr, G.F.
1958: The industrial minerals of Newfoundland. Department of Mines and Technical Surveys, Industrial Minerals Division, Mines Branch, No. 855. 158 pages [(NFLD 118)]

Coleman, A.P.
1921: Northeastern part of Labrador and New Quebec. Geological Survey of Canada, Memoir 124. [LAB (2)]

Douglas, G.V.
1953: Notes on localities visited on the Labrador coast in 1946 and 1947. Geological Survey of Canada, Paper 53-1, 67 pages. [Lab. (20)é

Fitzhugh, W.W.
1972: Environmental archaeology and cultural systems in Hamilton Inlet, Labrador. Smithsonian Contributions to Anthropology, Volume 16, Washington, 299 pages.

Geological Survey of Canada
1984: Regional lake sediment and water geochemical reconnaissance data, southeast Labrador, N.T.S. 3D, 13A, and parts of 2M and 12P. Geological Survey of Canada, Open File 1102, Newfoundland Department of Mines and Energy, Open File LAB 689.

1986: Regional lake sediment and geochemical reconnaissance survey for northern Labrador (parts of N.T.S. 14E, 14F, 14L, 24H, and 24I). Geological Survey of Canada, Open File 1210. Newfoundland Department of Mines, Open File LAB 695.

1987: Regional stream sediment and water geochemical reconnaissance data, northern Labrador (parts of 14L, 14M, 24I, 24P, and 25A). Geological Survey of Canada, Open File 1354. Newfoundland Department of Mines, Open File LAB 710.

Gower, C.F., Neuland,S., Newman, M. and Smyth, J.
1987: Geology of the Port Hope Simpson map region, Grenville Province, eastern Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 183-199.

Gower, C.F., Van Nostrand, T. and Smyth, J.
This volume: Geology of the St Lewis River map region, Grenville Province, eastern Labrador.

Grimley, P.H.
1959: Geological report of Ramah Area; Investigation of the chert horizon–Ramah Series. Unpublished report. BRINEX, 3 pages. [NFLD. 14L/14 (12)]

Knight, I. and Morgan, W.C.
1976: Stratigraphic subdivision of the Aphebian Ramah Group, Northern Labrador. Geological Survey of Canada, Paper 77-15, 31 pages.

Knight, I. and Morgan, W.C.
1981: The Aphebian Ramah Group, Northern Labrador; *In* Proterozoic Basins of Canada. *Edited by* F.H.A. Campbell. Geological Survey of Canada, Paper 81-10, pages 313-330.

Lazenby, M.E.C.
1980: Prehistoric sources of chert in Northern Labrador: Field work and preliminary analyses. Arctic, Volume 33, pages 628-645.

Miller, R.R.
1986: Geology of the Strange Lake alkalic complex and the associated Zr-Y-Nb-Be-REE mineralization. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 11-19.

Morgan, W.C.
1975: Geology of the Precambrian Ramah Group and basement rocks in the Nachvak Fiord-Saglek Fiord Area, Northern Labrador. Geological Survey of Canada, Paper 74-54, 41 pages.

Rivers, T.
1978: Geological mapping of the Wabush-Labrador City area, Southwestern Labrador. *In* Report of Activities. Department of Mines and Energy, Mineral Development Division, Report 78-1, pages 44-50.

Ryan, A.B., Martineau, Y., Bridgewater, D., and Schiotte, L. and Lewry, J.
1983: The Archean-Proterozoic boundary in the Saglek Fiord Area, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 91-98.

Wardle, R.J.
1987: Platinum-group-element potential in Labrador. *In* Current Research. Newfoundland Deparment of Mines and Energy, Mineral Development Division, Report 87-1, pages 211-224.

Ware, M.J.
1983: Depositional history and stratigraphy of the Aphebian Tamarack Formation and the Paleohelikian Sims Formation, Western Labrador. Unpublished M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland, 119 pages.

Ware, M.J. and Hiscott, R.N.
1985: Sedimentology of Proterozoic cratonic sheet sandstones of the eastern Canadian Shield: Sims Formation, Labrador, Canada. Precambrian Research, 30, pages 1-26.

Ware, M.J. and Wardle, R.J.
1979: Geology of the Sims-Evening Lake area, western Labrador, with emphasis on the Helikian Sims Group. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 79-5, 22 pages.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 261-271

DOLOMITE EVALUATION PROJECT

P.W. Delaney and A.F. Howse
Mineral Deposits Section

ABSTRACT

An assessment of insular Newfoundland's dolomite resource was initiated in 1987. The aim of the project is to identify deposits of metallurgical grade.

The Lower Ordovician, carbonate platform rocks of western Newfoundland host a number of high-purity dolomite deposits, most of which are located on tidewater. Deposits were investigated on the Port au Port Peninsula, at Goose Arm in the Bay of Islands, and at several localities on the Great Northern Peninsula.

INTRODUCTION

During the 1987 field season, a project was initiated aimed at locating and assessing potential metallurgical-grade dolomite deposits in the carbonate sequences of western Newfoundland. The objective was to locate a minimum deposit of 10 million tonnes of dolomite with 21 percent MgO, less than 1.5 percent SiO_2, total Al_2O_3 + Fe_2O_3 less than 1 percent, less than 200 ppm Mn, less than 10 to 15 ppm B, and low Cr. Suitable quarry sites and proximity to tidewater were also considered in the assessment.

Five major prospects (Figure 1) were mapped and sampled together with several other occurrences. Exploration was concentrated on the Lower Ordovician St. George Group, but some sampling was conducted on the Upper Cambrian Petit Jardin Formation of the Port au Port Group. Generally, chip samples were taken perpendicular to bedding over a maximum thickness of 5 m per sample using a 3.6-kg sledgehammer and 0.7-kg geology hammer to remove weathered surfaces. In areas of flat-lying bedding, it was sometimes possible to sample only the top bed. In such cases, the outcrop was sampled over a 5-m radius. Approximately 370 samples were collected; these will be analyzed for a range of chemical elements at the Newfoundland Department of Mines geochemical laboratory.

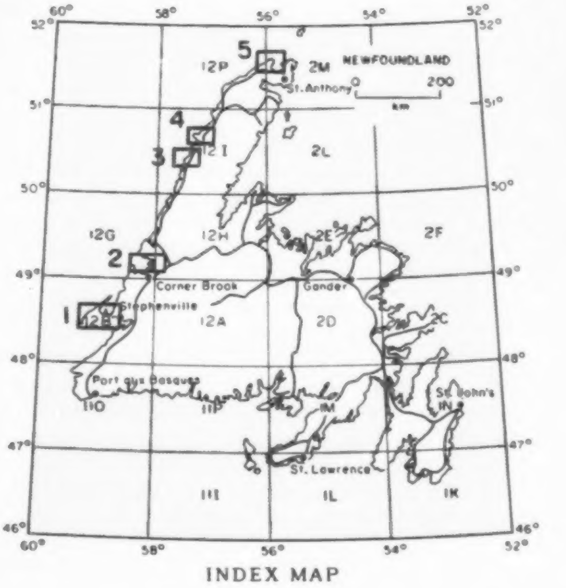


Figure 1. *Location of major dolomite prospects: 1) Port au Port Peninsula; 2) Goose Arm; 3) Deer Cove; 4) Port au Choix; 5) Cape Norman.*

Previous Work

Carbonate rocks of the Lower Ordovician St. George Group of Newfoundland's west coast have been studied extensively in recent years (Knight, 1977, 1985, 1986, 1987; Knight and Boyce, 1984; Knight *et al.*, 1983). Haywick and James (1984) studied the stratigraphic and geographic distribution of dolomite in the St. George Group and also documented its various textures. However, except for the early studies of Fong (1968), Besaw (1974), and DeGrace (1974), there has been little recent work to determine the economic potential of the dolomite. Fong's (1968) survey included the Port au Port Peninsula, Goose Arm, Deer Cove, and Port au Choix areas. Besaw (1974) studied the dolomite potential of the Port au Port Peninsula, and identified a unit of dolomite that he called the Pine Tree unit, as possibly hosting metallurgical-grade stone. This unit is equivalent to the dolomites of the Catoche Formation of Knight and James (1987).

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

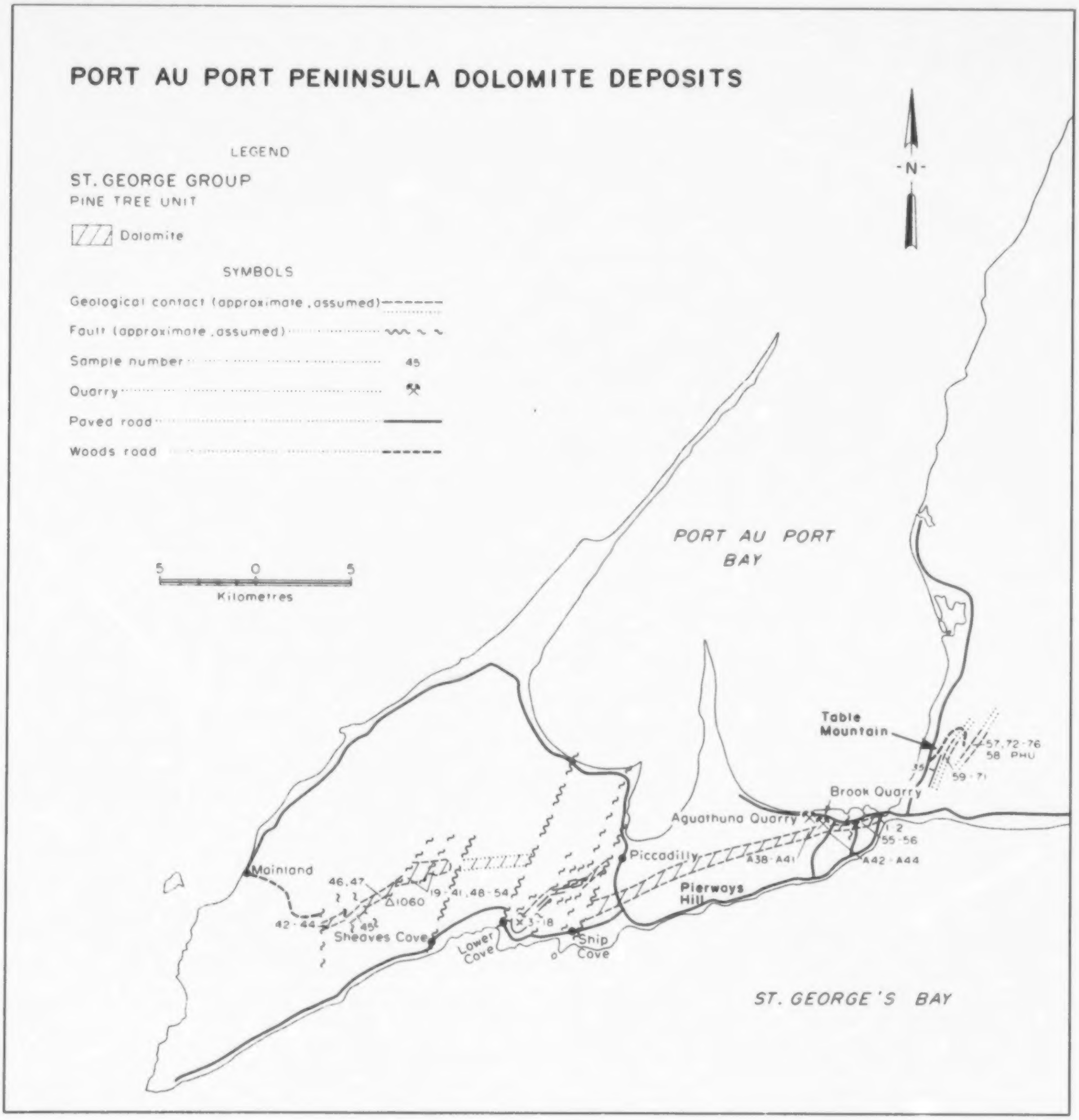

PORT AU PORT PENINSULA DOLOMITE DEPOSITS
LEGEND
ST. GEORGE GROUP
PINE TREE UNIT
▨ Dolomite
SYMBOLS
Geological contact (approximate, assumed)
Fault (approximate, assumed)
Sample number 45
Quarry ⚒
Paved road
Woods road
-N-
5 0 5
Kilometres
PORT AU PORT BAY
ST. GEORGE'S BAY
Table Mountain
57,72-76
58 PHU
59-71
35
Brook Quarry
Aguathuna Quarry
1-2
55-56
A38-A41
A42-A44
Piccadilly
Pierways Hill
Mainland
46,47
19-41,48-54
Δ1060
42-44
45
Sheaves Cove
Lower Cove
3-18
Ship Cove

Figure 2. *Location of dolomite deposits on the Port au Port Peninsula (geology modified from Besaw, 1974).*

More recently, Norsk Hydro conducted reconnaissance exploration for metallurgical-grade dolomite on the west coast of Newfoundland. The objective was to identify dolomite of sufficient quality for the production of magnesium oxide and magnesium metal.

PORT AU PORT PENINSULA

The informally named Pine Tree unit of the St. George Group has been the main focus of interest as a potential source of metallurgical-grade dolomite on the Port au Port Peninsula. The unit forms an east-west trending belt across the peninsula (Figure 2). Northeast-trending faults displace the unit giving rise to three areas of outcrop or belts. The unit is also exposed on the top of Table Mountain about 6 km northeast of the peninsula.

The Pine Tree unit is typically a buff or light-brown, fine- to medium-grained, massive dolomite. Chert is the main impurity and occurs as 1- to 5-cm diameter nodules, irregular masses or lenses that are often concentrated in discontinuous layers. Locally, thicker, more continuous layers of chert are present. Chert also occurs as 1- to 3-cm irregular masses intermixed with dolomite. Generally, the chert is most abundant in the lower 15 m of the unit. Bedding in the unit was almost obliterated during the dolomitization process, but a gentle northerly dip is assumed from overlying and underlying units.

The westernmost belt can be reached by a trail heading north from a point near Sheaves Cove, or off a woods road heading eastward from the community of Mainland. The belt is less than 200 m wide in the western half, but widens eastward, due in part to the combined effect of eastern and northeast-trending oblique-slip faults that bring together different levels and lateral portions of the belt. The cherty, lower 10 m of the Pine Tree unit is considered to underly the southern half of the more widely exposed section of the unit. Faulting is more evident here, and this, combined with some dissolution of the Pine Tree unit, has caused windows of the underlying Pigeon Head unit (Besaw, 1974) to occupy depressions and low ground. Dolomite in the northern half appears to be thicker and of better quality, although chert is still present. The top 2 to 3 m of the Pine Tree unit is only partly dolomitized, and consists of a fine grained burrowed limestone. It is the burrows that are locally dolomitized. Quartz crystals and iron staining are more abundant near the top contact, but calcite crystals are scattered throughout the belt. Natural quarry faces of 8 to 15 m are present in the western part of the belt, but the poor quality of the dolomite and rugged terrain, limit the feasibility of development.

The middle belt extends east-northeast from Lower Cove on the south coast to Piccadilly near the north coast. It is offset along several northeast-trending high-angle faults (Figure 2). Chert is a minor constituent through much of the thickness, but is more abundant in the lower part of the unit. Good quarry faces are present at Lower Cove and Piccadilly.

The belt between Ship Cove and the Port au Port isthmus is relatively undisturbed except for minor offset in the eastern portion by north-trending block faulting. Impurities consist of scattered chert nodules and calcite crystals. The roadcut at the isthmus shows an incompletely dolomitized rock consisting of intermixed fine grained burrowed limestone and mottled dolomite on a scale of metres. This incomplete dolomitization continues westward for about 3 km. The terrain throughout this belt is rather flat with few natural quarry sites although the Brook Quarry at Aguathuna can easily be expanded.

The Pine Tree unit as exposed on Table Mountain east of the Port au Port Peninsula (Figure 2), consists of two northeast-trending belts on either side of the mountain. Only the exposures southwest and southeast of the communication facilities at the top of the mountain were mapped and sampled, although the unit is probably exposed farther north along the mountain top. The unit dips 35° northwest and is approximately 10 m thick. The dolomite is vuggy and variably burrowed. Locally, the rock contains only dolomitized burrows. Calcite partially fills 1-cm-diameter vugs, and occurs as coatings on fractures and as 1- to 2-cm blocky crystals. It also forms an intergranular cement to the dolomite, and when absent, the dolomite has abundant intergranular space and often a very crumbly texture. Chert commonly occurs as 1- to 20-cm diameter nodules and lenses, generally concentrated in discontinuous layers up to 8 cm thick. Locally, dolomite grains are coated with white clay.

Port facilities are not presently available on the Port au Port Peninsula, but Bay St. George is relatively ice-free and should be adequate for year-round shipping. Port au Port Bay was once used to ship limestone from the Aguathuna Quarry but the dock no longer exists. The bay is usually filled with drift ice during the spring.

GOOSE ARM

Large quantities of fair- to good-quality dolomite were located in the Goose Arm area of the Bay of Islands (Figures 1 and 3). There are at least five potential deposits along Goose Arm and Penguin Arm, namely: 1) Penguin Cove; 2) South Goose Arm; 3) The Narrows; 4) Penguin Hills and 5) Penguin Arm deposits. A sixth site, the Goose Arm Road deposit, can be accessed by a woods road from Deer Lake.

The Hughes Brook Formation of dolostones and shaly dolostones (Lilly, 1963) is the unit of interest in the Goose Arm area. The Hughes Brook Formation is a correlative of the Berry Head Formation of the Port au Port Group (Chow and James, 1987) and the Watts Bight and Boat Harbour formations of the St. George Group (Knight, personal communication).

The dolomite is typically very hard, massive, light grey, very fine grained and medium to thick bedded. Chert, calcite and quartz are rare in the dolomite but in three of the deposits (3, 5 and 6 in Figure 3) the dolomite has been cut by numerous quartz veins up to 1 cm thick. Generally, they are spaced less than 20 cm apart and may follow one main trend or several trends. Interbedded shale was only seen on the woods road north of the head of Goose Arm.

The following are brief descriptions of sampled Goose Arm dolomite deposits considered to be of potential metallurgical grade. Chemical analyses of the samples, currently in progress, will help decide which deposits warrant follow-up work.

Penguin Cove Deposit

The purest dolomite deposit occurs east of Penguin Cove where beds of dolomite about 1 m thick, dipping 20° east (Plate 1), are exposed in a 150-m-high vertical cliff. Approximately 75 m of bedding are exposed along the shore and 11 samples were taken perpendicular to bedding over a thickness of 5 m each. This section of the Hughes Brook Formation varies from dark grey, generally massive dolomite,

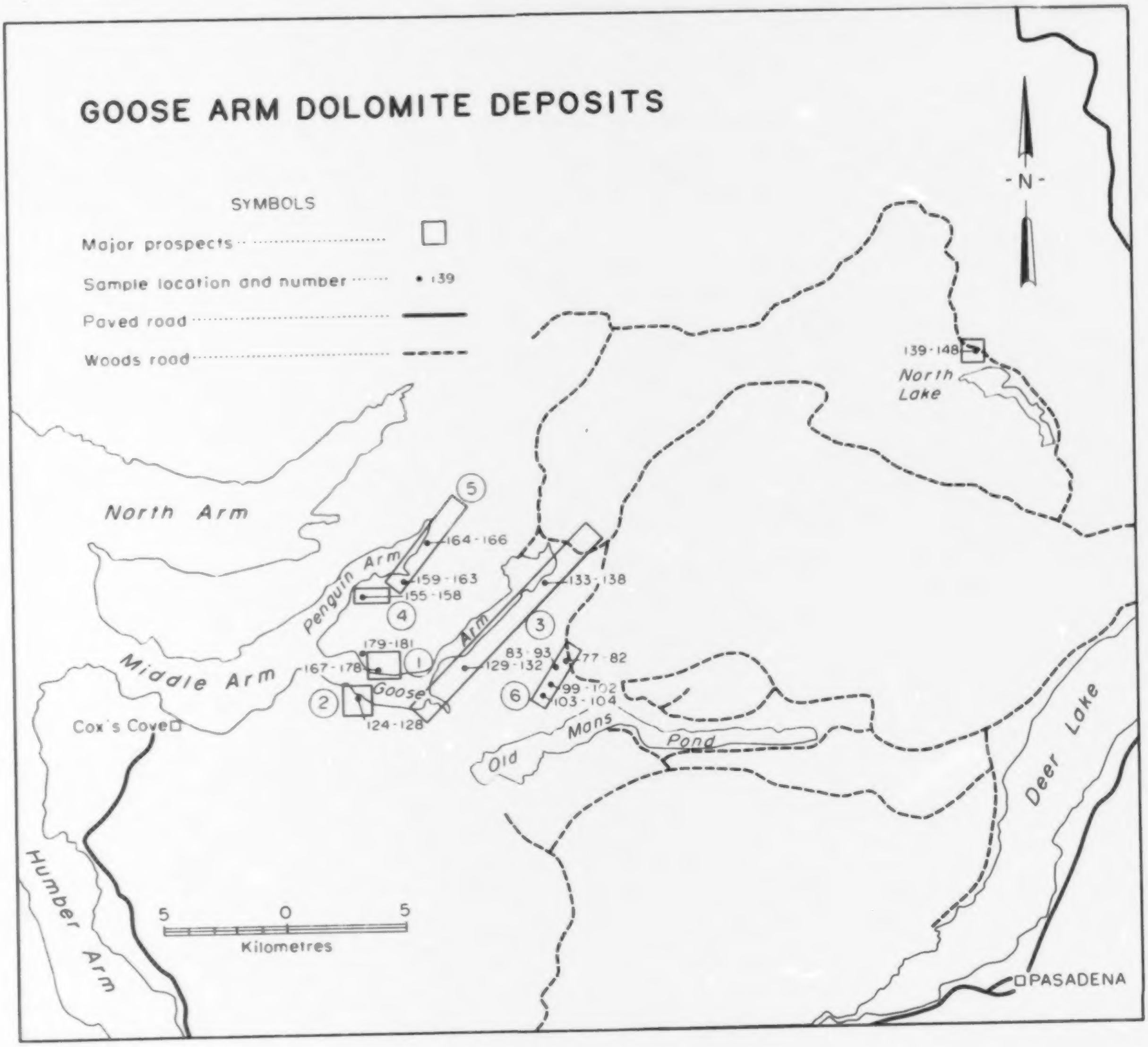

GOOSE ARM DOLOMITE DEPOSITS
SYMBOLS
Major prospects
Sample location and number • 139
Paved road
Woods road
- N -
139-148
North Lake
North Arm
Penguin Arm
Middle Arm
Goose Arm
Cox's Cove
Old Mans Pond
Deer Lake
Humber Arm
PASADENA
164-166
159-163
155-158
179-181
167-178
124-128
133-138
83-93
129-132
77-82
99-102
103-104
①
②
③
④
⑤
⑥
5 0 5
Kilometres

Figure 3. *Goose Arm dolomite prospects.*

but with some beds heavily cleaved in the lower 25 m of the section, to a light grey, stylolitic dolomite in the upper part. Impurities were noted in only one sample that contained trace amounts of fine grained pyrite and probable chlorite. Lilly (1963) also reported flecks of galena and sphalerite in the cliff face and noted silty laminations that may represent stylolites. Galena and pyrite also occur in dolomite to the west in Penguin Cove.

The contact between the Hughes Brook Formation and sandstones and shales of the Penguin Cove Formation, which was considered by Lilly (1963) to be conformable within an anticline, is here considered to be a high-angle fault contact, possibly with an anticline structure. To the east, the Hughes Brook Formation is conformably overlain by fine grained, burrowed limestones of the Corner Brook Formation (equivalent to the Catoche Formation of Knight and James, 1987).

Goose Arm South Deposit

An approximately 85-m-thick section of Hughes Brook dolomite is exposed along the shore due south across Goose Arm from the Penguin Cove deposit. The dolomite dips 42° east and has a conformable eastern contact with a fine grained burrowed limestone, and a high-angle fault contact with steeply west-dipping (65-70°) black shale and limestone on the west. The dolomite is similar to the Penguin Cove deposit but the vertical stratigraphic change in lithology and cleaved beds observed at the Penguin Cove deposit were not observed in this section. The dolomite near the fault contact is iron stained and consists of clasts of grey dolomite set in a creamy,

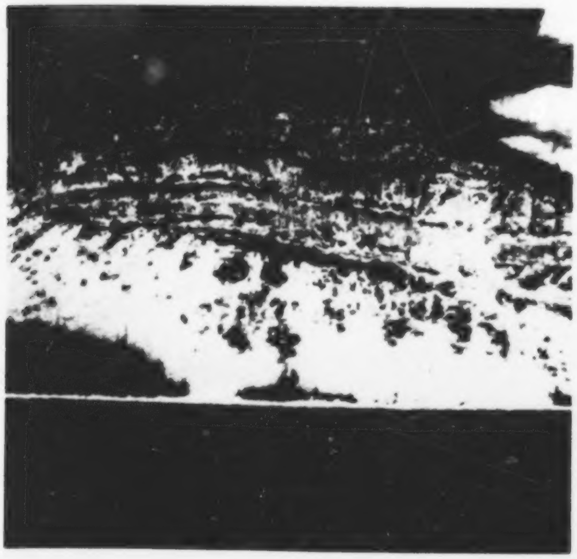


Plate 1. *Thick-bedded dolomite of the Hughes Brook Formation exposed in an approximately 150-m-high cliff east of Penguin Cove, Goose Arm.*

coarse grained vuggy dolomite matrix. The land surface rises rapidly away from the shore, indicating that significant tonnage may be present at this site.

The Narrows Deposit

The Narrows dolomite deposit outcrops in northeast-trending cliffs up to 230 m high that parallel the strike of Goose Arm (Plate 2). The dolomite is predominantly massive but fine laminations and an oolitic bed are also present in the section. Extensive quartz veins less than 1 cm thick, dipping 35° northeast are present. Calcite locally coats fractures. An approximately 60-m-thick section of horizontally bedded dolomite is located near the head of Goose Arm. A probable fault separates it from the main cliff section. The horizontal beds contain no quartz veins. Bedding in the rest of the deposit is vertical and trends 050°, roughly the same strike as the cliffs. The stratigraphic thickness of the cliff section is hard to define, but Lilly (1963) puts the thickness of the Hughes Brook Formation in the Goose Arm area at more than 400 m. Thick wedges of talus at the base of the cliffs could also be extracted. Reserves of over 100 million tonnes are estimated from the entire 6-km-long cliff exposure.

Penguin Hills Deposit

This site consists of heavily cleaved, laminated dolomite with cobble-sized pieces of dolomite in the talus slope. Rare 1-mm-diameter quartz grains and 1- to 2-cm-diameter clumps of grey or brown clay are present in the dolomite. The beds dip 20° north. More than 10 million tonnes of dolomite are estimated for this deposit.

Plate 2. *Dolomite cliffs, about 200 m high, at the narrows of Goose Arm.*

Penguin Arm Deposit

Hughes Brook Formation dolomite outcrops in cliffs on the north and south side of Penguin Arm. The unit is also continuously exposed in cliffs along the east side of Penguin Arm for another 2 to 3 km. South of Penguin Arm, the cliff exposes at least 30 m of dolomite dipping 65° northwest. At this locality, the dolomite contains solitary blocky crystals of pink dolomite and zones containing clasts of fine grained dolomite set in a coarse grained dolomite matrix. No visible impurities were noted in outcrop but chert was observed in the talus slope at the base of the cliff. Near the head of Penguin Arm, the dolomite is extensively veined by quartz and calcite trending in several different directions. More detailed assessment, including diamond drilling, would be required to accurately define the high-purity dolomite zones in this area.

Goose Arm Road Deposit

A deposit of good quality dolomite was identified and sampled along a woods road about 5 km east of Goose Arm. A roadcut exposes a minimum stratigraphic thickness of 60 m of medium-bedded stone dipping 42° northeast. It is cut by up to 1 cm thick dolomite veins and local quartz veins. This block of dolomite is separated from a larger block to the west by a northeast-trending fault. The northwest and south sides of this larger block (40,000 m^2 in plan view) consist of 30-m cliffs (Plate 3) that encompass an area of approximately 400 m by 100 m. The dolomite beds are vertically dipping and contain extensive quartz veins with widths up to 1 cm. A 1- to 2-m-thick bed containing up to a few percent rounded quartz grains is also present.

Plate 3. *Thirty-m-high cliffs along the south side of the larger block of dolomite; Goose Arm Road.*

The woods road that provides access to the dolomite connects to the Deer Lake–Nicholsville road near the northeast tip of Deer Lake. Although the area is particularly well suited, topographically, for quarrying, additional work is required to define more precisely the size and quality of the deposits.

GREAT NORTHERN PENINSULA

Deer Cove Deposit

This deposit is located approximately 5 km north of Bellburns on the Great Northern Peninsula between the Viking Trail (Route 430) and the sea (Figures 1 and 4). The dolomite comprises a section of the Catoche Formation of the Lower Ordovician St. George Group. The flat-lying to gently westerly dipping beds are up to 2 m thick. The dolomite has a fine- to medium-grained crystalline texture and is varible in colour from light- to dark-grey-brown. A maximum thickness of 20 m is exposed along the coast; the deposit can be traced at least 3 km along a northerly strike but only about 200 m inland. This represents a deposit of nearly 35 million tonnes.

The Deer Cove deposit is located on an exposed area of the coast where the nearest harbour and shipping facilities are found at Hawkes Bay, 40 km to the north. Work carried out to date, including Fong's (1968) assessment, indicates a high degree of variation in the silica content of the dolomite along its strike. In order to determine an accurate grade for this deposit, a follow-up assessment including drilling will be required.

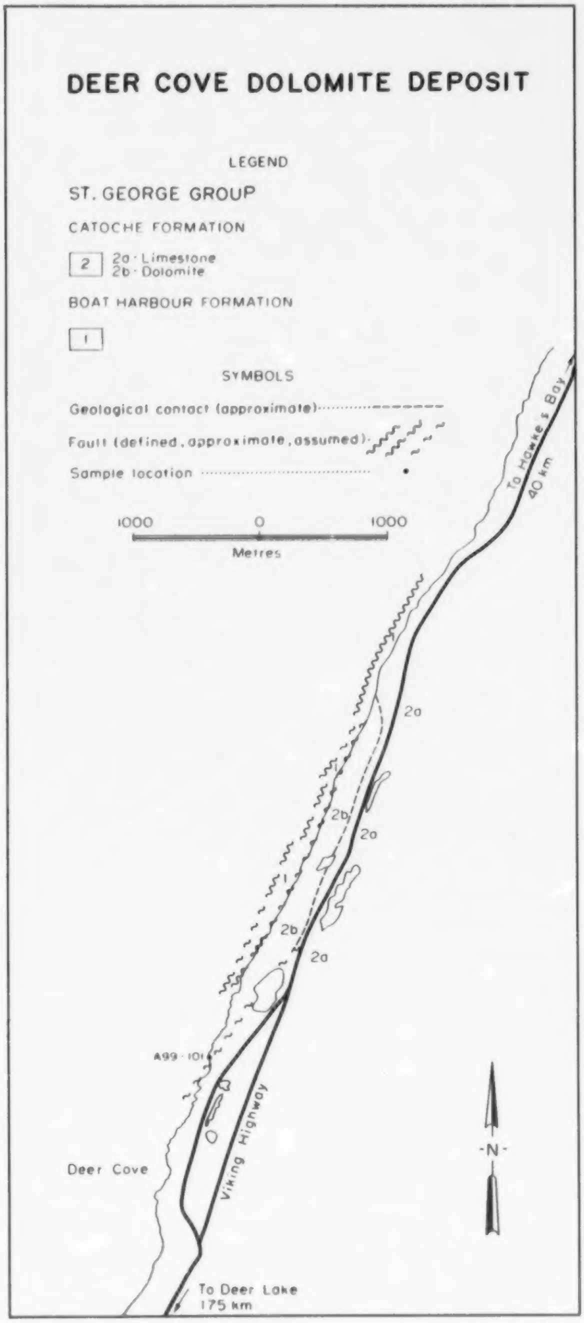

DEER COVE DOLOMITE DEPOSIT
LEGEND
ST. GEORGE GROUP
CATOCHE FORMATION
2
2a · Limestone
2b · Dolomite
BOAT HARBOUR FORMATION
1
SYMBOLS
Geological contact (approximate)
Fault (defined, approximate, assumed)
Sample location
1000
0
1000
Metres
To Hawke's Bay 40 km
2a
2b
2a
2b
2a
1
1
A99 · 101
Viking Highway
Deer Cove
N
To Deer Lake 175 km

Figure 4. *Deer Cove dolomite deposit (geology after Knight, 1985). Geology seaward of strand line is based on low-tide exposures.*

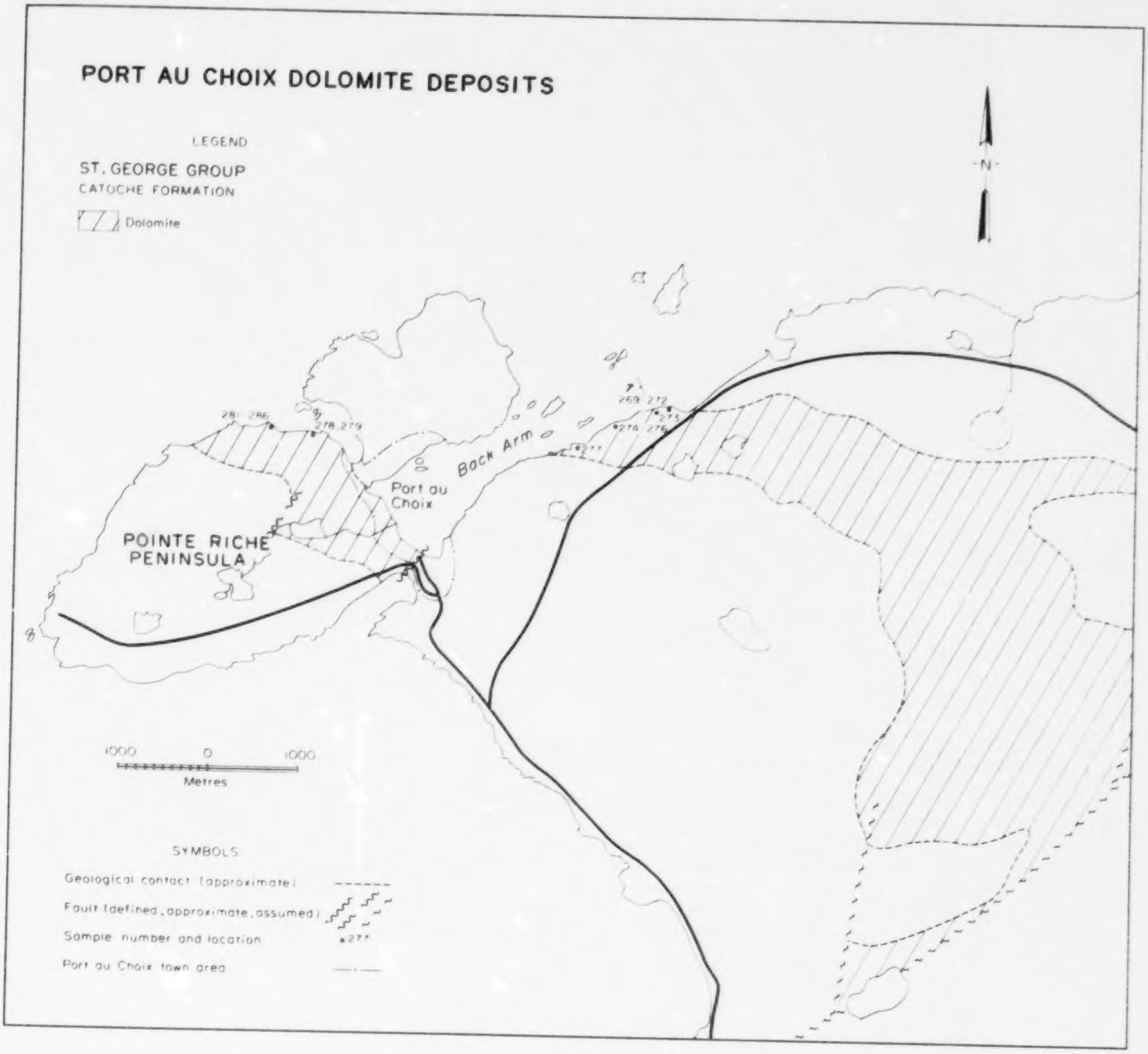

PORT AU CHOIX DOLOMITE DEPOSITS
LEGEND
ST. GEORGE GROUP
CATOCHE FORMATION
Dolomite
N
281-286
278-279
269-272
273
274-276
277
Back Arm
Port au Choix
POINTE RICHE PENINSULA
1000
0
1000
Metres
SYMBOLS
Geological contact (approximate)
Fault (defined, approximate, assumed)
Sample number and location
•277
Port au Choix town area

Figure 5. *Port au Choix dolomite deposits (geology after Knight* et al., *1983).*

Back Arm Deposit

This site, on the east side of Back Arm near the town of Port au Choix (Figure 5), consists of a gently (5 to 10°) southwest-dipping, 16-m-thick section of Catoche Formation dolomite. It is buff to medium brown and is variably mottled and vuggy. The dolomite is medium to thick bedded and has a fine- to medium-grained texture. Vugs constitute less than 1 percent of the rock but in some beds or locally within a bed, comprise approximately 25 percent of the rock. The more intensely vuggy zones are characterized by 1- to 2-cm diameter vugs and a texture that may relate to burrowing. The medium grained portions have abundant intergranular space, which, along with the vugs, are partly filled with black organic material. Vugs in the more massive rock are lined with either quartz or dolomite in equal proportions and rarely contain calcite crystals. Chert, up to 1 percent in content, also occurs as 1- to 4-cm diameter nodules that are most abundant in the upper portions of the section. The unit underlies a large area to the east of Back Arm and, although natural quarry faces are not present, it may be possible to develop a quarry site.

Pointe Riche Deposit

The deposit is located on the northern part of the Pointe Riche Peninsula, 30 km northwest of Hawke's Bay (Figure 5). It comprises a 17-m-thick section of dolomite that is lithologically similar to the Back Arm deposit. The deposit comprises a large area and sufficient tonnage should be present for quarrying. However, this deposit lies within the boundaries of the Port au Choix National Historic Park and may not be available for development.

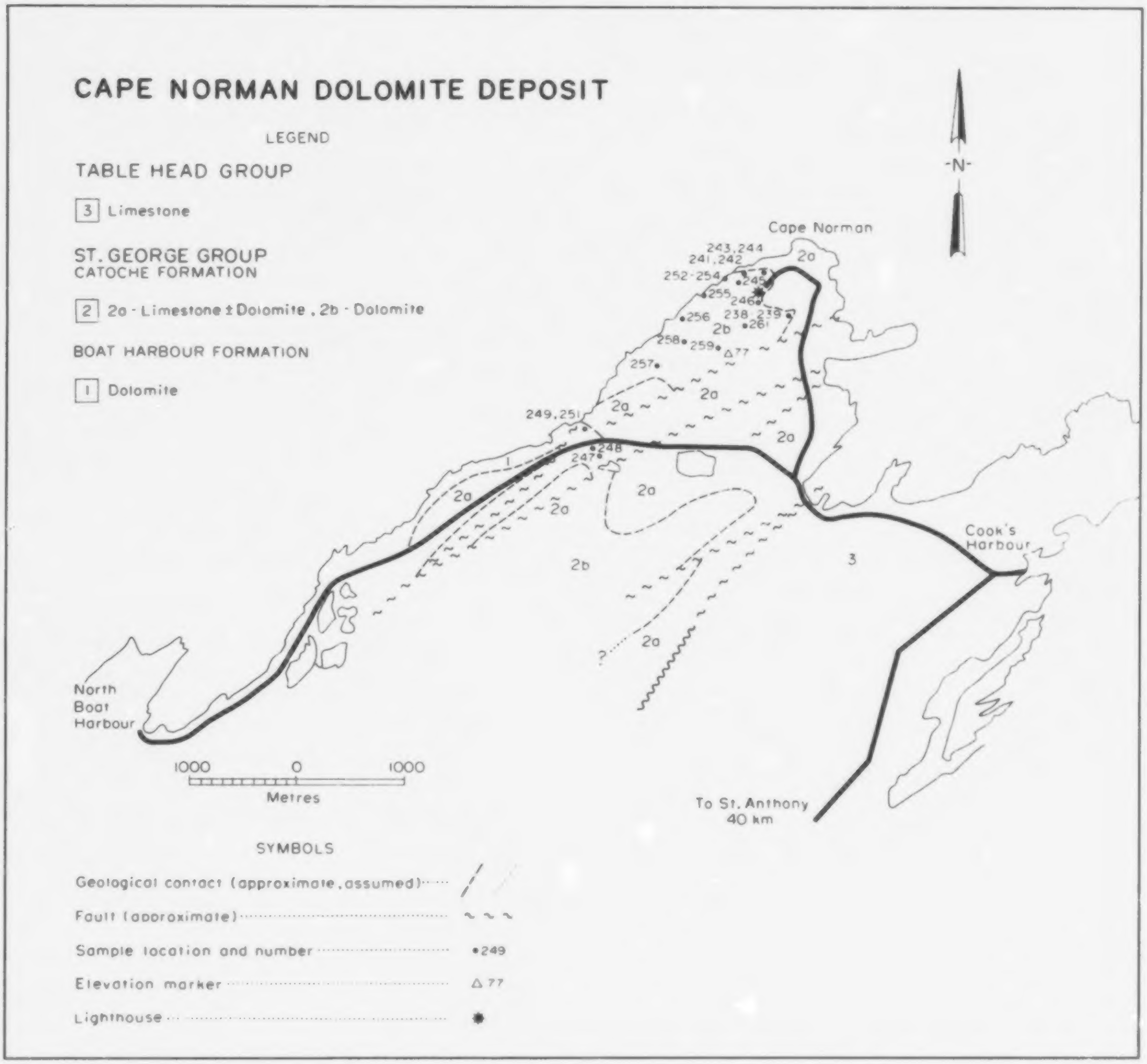

CAPE NORMAN DOLOMITE DEPOSIT
LEGEND
TABLE HEAD GROUP
3 Limestone
ST. GEORGE GROUP
CATOCHE FORMATION
2 2a - Limestone ± Dolomite, 2b - Dolomite
BOAT HARBOUR FORMATION
1 Dolomite
-N-
Cape Norman
243,244
241,242
252-254
245
255
246
256
238
239
2b
261
258
259
△77
257
2a
249,251
248
247
1
2a
2a
2a
2a
2b
3
Cook's Harbour
2a
North Boat Harbour
1000 0 1000
Metres
To St. Anthony 40 km
SYMBOLS
Geological contact (approximate, assumed)
Fault (approximate)
Sample location and number •249
Elevation marker △77
Lighthouse

Figure 6. *Cape Norman dolomite deposit (geology after Knight, 1986).*

Seasonal shipping facilities for the Port au Choix deposits are available at Hawke's Bay.

Cape Norman Deposit

The Cape Norman deposit is located on the tip of the Great Northern Peninsula and occurs in the Catoche Formation of the St. George Group (Figures 1 and 6). The dolomite is grey, fine grained, massive and very thick bedded. The gently warped unit is approximately 15 m thick, has no overburden (Plate 4) and has a good quarry face on the coast, west of the lighthouse (Plate 5). The lower 5 m of the section contains abundant lenticular vugs, usually 1 to 2 cm long but rarely up to 20 cm. Vugs in this part of the section are partly lined with quartz or dolomite. Impurities through the rest of the section consist of scattered clumps of fine grained quartz and chert. The Cape Norman deposit is conservatively estimated at 35 million tonnes of good grade metallurgical dolomite. No shipping facilities exist in the immediate area of Cape Norman. However, at Cooks Harbour, 5 km to the southeast, there is potential for port development.

Other Areas Sampled on the Great Northern Peninsula

Sampling was conducted on the Catoche and Watt's Bight formations of the St. George Group, and the Petit Jardin Formation of the Port au Port Group at the following locations: 1) Roddickton area; 2) Big Brook; 3) New Ferolle Peninsula; 4) Ten Mile Lake and 5) Castor's River. These areas are shown in Figure 7.

Plate 4. *Barren, massive dolomite of the Catoche Formation at Cape Norman; maximum relief on this barren plain about 1.5 m.*

Plate 5. *Cliffs of Catoche Formation, about 20 m high, at Cape Norman.*

Roddickton area: Dolomite of the Catoche Formation was sampled along the highway north of Roddickton. The dolomite is fine to medium grained and very vuggy. Grain-size difference and vugginess in the mottled dolomite are probably the result of an originally burrowed rock. The coarser dolomite is typically light grey and has abundant vug space up to 5 mm. Iron staining is common but minor.

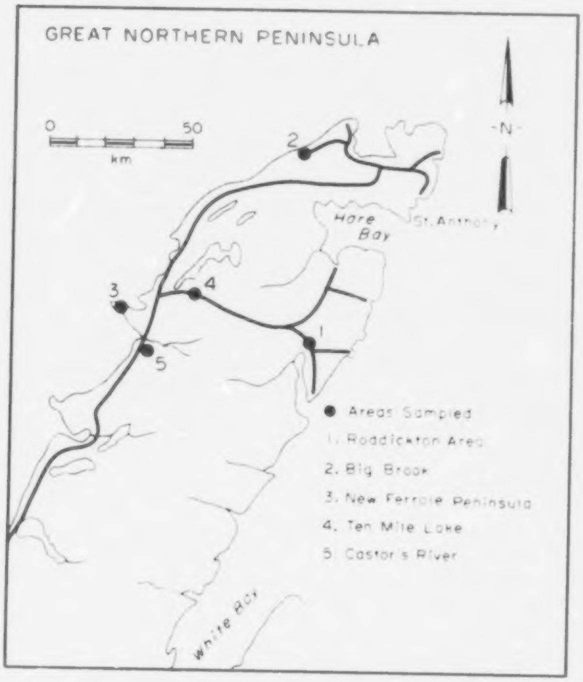


Figure 7. *Location of other dolomite prospects investigated in 1987.*

Sampling in the Roddickton area included the Watt's Bight Formation, which in this area is a grey, fine grained, medium- to thick-bedded, massive dolomite. The rock contains variable amounts of black chert as lenses and nodules, and quartz and calcite crystals. Minor pyrite and sphalerite were also observed.

Low topographic relief in the Roddickton area would be a problem in developing a quarry site.

Big Brook: North of Big Brook, two coastal exposures of the Watts Bight Formation were sampled, and in one of the areas approximately 2 m of the underlying Petit Jardin Formation was also sampled. In both localities, the Watts Bight Formation consists of brown, fine grained, massive to laminated, thin- to thick-bedded dolomite containing discontinuous beds of mixed chert and dolomite. Chert nodules 2 to 3 cm in diameter are scattered throughout the section. The Petit Jardin dolomite is grey to buff, fine grained and mottled and contains chert nodules and 10-cm-diameter rounded masses of fine grained quartz.

New Ferolle Peninsula: The Watts Bight Formation was sampled on the New Ferolle Peninsula. At this locality it consists of brown, fine grained, variably mottled and vuggy dolomite. Vugs are partly or completely filled with white or creamy dolomite crystals and locally the vugs are connected by 1-mm white dolomite veinlets producing pseudobrecccia texture. Chert is a common impurity occurring as irregularly shaped masses (1 to 5 cm long) or as discontinuous layers up to 30 cm thick. Quartz and white clay coatings on grains are locally present. The New Ferolle Peninsula is characterized by very low relief, which is not amenable for quarry operations. However, on the western side of the peninsula, broad hills rise 15 to 16 m above sea level.

Ten Mile Lake: In a road cut and abandoned quarry near Ten Mile Lake, sampling was conducted on a 10-m-thick section of grey, fine grained massive dolomite of the Petit Jardin Formation. Two 20-cm-thick beds of dark grey shale occur in the quarry face.

Castor's River: The Watts Bight Formation was also sampled in roadcuts and an abandoned road quarry along the Viking Trail north of Castor's River. The grey dolomite is fine- to coarse-grained, medium bedded and massive, laminated and vuggy. Dolomite veins intrude along several cleavage trends. Chert occurs in 1- to 2-m irregularly surfaced beds containing angular, pebble- to boulder-sized clasts of limestone and dolomite set in a coarse grained creamy dolomite. Chert comprises approximately 25 percent of the beds. Disseminated pyrite is present in the dolomite and along fracture planes.

SUMMARY

Detailed geological mapping and sampling were conducted on various deposits of dolomite on the west coast and Great Northern Peninsula of Newfoundland. The objective was to identify deposits of metallurgical grade, located on tidewater, and suitable for quarrying. Five areas of good potential were outlined, most of which occur within the Lower Ordovician St. George Group. These areas are: 1) the Port au Port Peninsula; 2) Goose Arm; 3) Deer Cove; 4) Port au Choix and 5) Cape Norman.

The Pine Tree unit between Piccadilly and Lower Cove on the Port au Port Peninsula offers sufficent tonnage, good grade, good quarry face and proximity to tidewater.

In the Goose Arm area, large tonnages are present at tidewater in five separate deposits. Relief is excellent in all deposits, but in some, the large amount of silica in the form of quartz veins may be detrimental to development. A sixth deposit occurs 5 km inland along a woods road and has good relief and tonnage but possibly high silica.

The Deer Cove deposit is poorly located on a straight unsheltered section of coastline. The nearest good harbour is 40 km to the north at Hawkes Bay. Also, the deposit has a flat topography and is thus not a good site for quarrying.

At Port au Choix, two deposits with similar features occur. They both underlie areas large enough to provide sufficient quantities of good-grade dolomite. Relief is low but the rock may be quarryable. Shipping facilities are available at Hawkes Bay, 30 km to the south. One deposit lies within the Port au Choix National Historic Park and thus may be unavailable for development. The Cape Norman deposit has good tonnage, good grades and a quarry face on the western shore. The ore would have to be trucked, or shipping facilities developed. Ice would be a problem to shipping in the area for much of the year.

All of the deposits described, before being considered for development, will require additional systematic evaluation, including diamond drilling, to determine accurate grades and tonnages.

ACKNOWLEDGMENTS

This paper was reviewed and significantly improved by Baxter Kean. During the field season, good assistance was provided by Eric Ebsary. The administrative staff of the Department of Mines are thanked for logistical support.

REFERENCES

Besaw, D.M.
1974: Limestone-dolomite evaluation. Newfoundland Department of Mines and Energy, Mineral Development Division. Unpublished report, 21 pages.

Chow, N. and James, N.P.
1987: Cambrian Grand Cycles: a northern Appalachian perspective. Geological Society of America Bulletin, Volume 98, pages 418-429.

DeGrace, J.R.
1974: Limestone resources of Newfoundland and Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 74-2, 117 pages.

Fong, C.C.K.
1968: Preliminary report on dolomite exploration, western Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division. Unpublished report, 7 pages.

Haywick, D.W. and James, N.P.
1984: Dolomites and dolomitization of the Lower Ordovician St. George Group of western Newfoundland. In Current Research, Part A, Geological Survey of Canada, Paper 84-1A, 6 pages.

Knight, I.
1977: The Cambrian-Ordovician platformal rocks of the Northern Peninsula. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-1, pages 27-34.

1985: Geology map of Bellburns (12I/5,6), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 85-63.

1986: Geology map of Raleigh (2M/12), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 86-26.

1987: Geology of the Roddickton (12I/16) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 343-357.

Knight, I. and Boyce, D.
1984: Geological mapping of the Port Saunders (12I/11), St. John Island (12I/14) and parts of the Torrent River (12I/10) and Bellburns (12I/6) map sheets, northwestern Newfoundland. In Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-1, pages 114-123.

Knight, I. and James, N.P.
1987: The stratigraphy of the Lower Ordovician St. George Group, western Newfoundland: the interaction between eustacy and tectonics. Canadian Journal of Earth Sciences, Volume 24, pages 1927-1951.

Knight, I., Boyce, W.D. and Austin, K.
1983: Geology map of Port Saunders (12I/11), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 83-111.

Lilly, H.D.
1963: Geology of the Hughes Brook–Goose Arm area, west Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, 122 pages.

Current Research (1988) Newfoundland Department of Mines
Mineral Development Division, Report 88-1, pages 273-278

MARBLE ASSESSMENT PROJECT–1987

A.F. Howse
Mineral Deposits Section

ABSTRACT

Marble deposits of potential commercial interest on Newfoundland's Great Northern Peninsula occur within a continuous belt from Canada Bay in the south to about 10 km south of Hare Bay in the north, a distance of more than 50 km. Two of these deposits, located at Penny's Pond and Coles Pond, have been shown by diamond drilling to contain at least three million tonnes of high-purity marble. The purity and size of these deposits, and their proximity to deep-water ports, have focused attention on this region as a potential primary source of high-purity marble for use in such industrial applications as mineral fillers and whiteners.

The marble occurs along deformed zones of St. George Group carbonate rocks that underlie the Hare Bay Allochthon. South of Hare Bay, erosion of the allochthon has exposed a 20-km-long belt of recrystallized dolomite and limestone, known as the White Arm Window. Locally, within the window, the limestones have been altered into white to grey marble. Several deposits of this marble were examined in 1987.

Occurrences of recrystallized limestones and dolomites of the St. George Group were also assessed in the Pinchgut Lake area south of Corner Brook.

INTRODUCTION

Work completed in the 1987 field season concluded a 3-year assessment of Newfoundland's marble resource. The objectives of the study were to identify and document marble deposits and determine potential industrial uses. The project began with an island-wide survey that included extensive sampling of high-purity marble deposits in western Newfoundland. This work resulted in the identification of several promising prospects. One of these, the Penny's Pond deposit near Roddickton (Figure 1), was selected for follow-up mapping and diamond drilling. This drilling delineated significant reserves of high-purity marble that may be suitable for use in the filler and whitener industries (Howse, 1987). A similar deposit was discovered and drilled near Coles Pond, 10 km north of Penny's Pond. The Newfoundland Department of Mines has invited proposals for the development of both of these deposits.

In 1987, the zone of documented marble occurrences was extended, as a result of the investigation of showings north of Coles Pond and west of Croque (Figure 1). Most of these deposits lie in a belt of Lower to Middle Ordovician carbonate rocks known as the White Arm Window (Smyth, 1971; Stouge, 1983a). Access to this region is by a gravel road linking the communities of St. Julien's and Croque on the eastern coast of the Great Northern Peninsula with the Roddickton–Main Brook highway (Route 432). Logging roads and trails branching off the main roads provide additional access. Deep-water harbours, though lacking in shipping facilities, exist at Roddickton, Croque, and Hare Bay.

A belt of recrystallized dolomite and limestone, south of Pinchgut Lake near Corner Brook, was also investigated in 1987. Some minor occurrences of white marble and more extensive zones of dolomitic marble were identified and sampled for chemical and physical analyses.

All samples collected during the 1987 field season have been sent to the Newfoundland Department of Mines geochemical laboratory for chemical analyses. Selected samples will be tested for brightness. The results will be included in a report to be published on Newfoundland's marble resource.

WHITE ARM WINDOW MARBLE

Geological Setting

The Hare Bay Allochthon has been eroded from White Arm Pond southward to expose an approximately 20-km-long belt of carbonate rocks known as the White Arm Window (Smyth, 1971) (Figure 2). Stouge (1983a) divided the carbonate rocks within the window into the Brent Island and Southern Arm formations of the Lower Ordovician St. George Group.

Interbedded grey to black limestone and grey dolomite of the Middle Ordovician Table Head Group underlie the northern part of the window.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

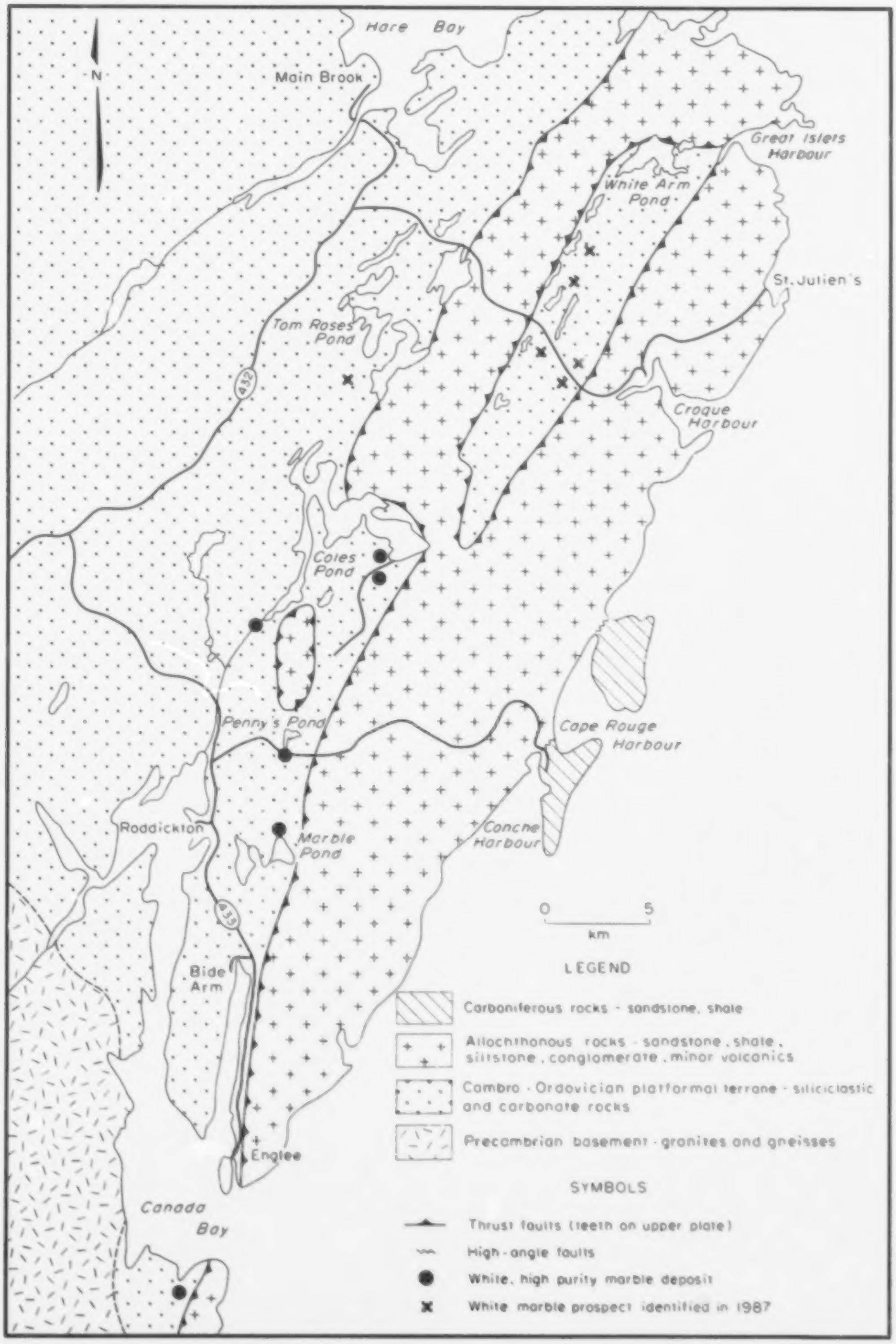
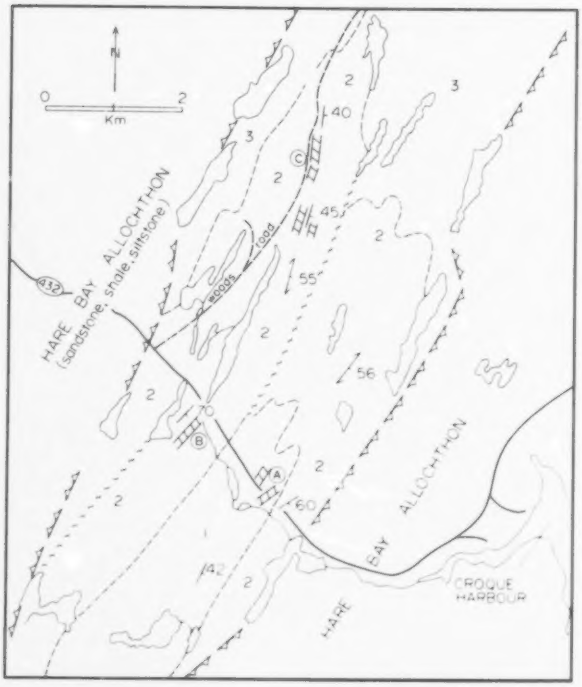

N
Hare Bay
Main Brook
Great Islets Harbour
White Arm Pond
St. Julien's
Tom Roses Pond
432
Croque Harbour
Coles Pond
Penny's Pond
Cape Rouge Harbour
Roddickton
Marble Pond
Conche Harbour
433
Bide Arm
Englee
Canada Bay
0 5
km
LEGEND
Carboniferous rocks - sandstone, shale
Allochthonous rocks - sandstone, shale, siltstone, conglomerate, minor volcanics
Cambro - Ordovician platformal terrane - siliciclastic and carbonate rocks
Precambrian basement - granites and gneisses
SYMBOLS
Thrust faults (teeth on upper plate)
High-angle faults
White, high purity marble deposit
White marble prospect identified in 1987

Figure 1. *Geological elements of the Canada Bay–Hare Bay region showing location of white marble deposits. Geology simplified after Knight (1987) and Stouge (1983a,b).*



LEGEND

MIDDLE ORDOVICIAN

Table Head Group

3 *Interbedded grey to black limestone and grey dolomite*

LOWER ORDOVICIAN

St. George Group

2 Southern Arm Formation: *interbedded limestone and dolomite*

1 Brent Island formation: *medium-bedded limestone, minor dolomite*

SYMBOLS

Strike and dip of bedding

Strike and dip of cleavage

Thrust faults (teeth on upper plate)

High-angle faults (assumed)

Conformable contact

White to light grey marble

Figure 2: *Location of white marble deposits in the White Arm Pond Window. Letters refer to deposits described in text: A–Powerline, B–Skidder Trail, and C–Sawmill. Geology after Stouge (1983a).*

Northeast-trending faults cut the sequence, and the carbonate rocks display a strong northeast-trending regional cleavage. The limestones and dolomites on the eastern and western margins of the White Arm Window in particular, have been recrystallized into fine- to medium-grained crystalline carbonates. Locally, the limestones have been sheared and bleached by metamorphism into white and grey marble. Several such deposits were investigated in 1987. For convenience, the more significant deposits were informally named the Powerline, Skidder Trail and Sawmill deposits; these are described separately below.

Powerline Deposit

Bands of white, grey and blue marble are exposed north and south of the Croque road near the eastern margin of the White Arm Window (Figure 2). The Croque power transmission line crosses the deposit.

The marble occurs within interlayered limestones and dolomites of the Brent Island formation. The marble is part of the northeast-trending, tightly folded sequence of dolomites and limestones exposed on the north and south sides of the Croque road.

The purest marble occurs just a few metres south of the road, where a 23-m-wide band has been exposed by road and powerline construction. The marble has a light-brown-weathered surface and is strongly cleaved (050°/40°SE). On fresh surfaces, the marble is white to buff and is fine grained. Bands of mica-rich impurities, 30- to 40-cm wide, were observed in some large loose blocks. Because of overburden, the marble cannot be traced along strike beyond a few metres. Thin-bedded recrystallized dolomite that occurs immediately above and below the white marble strikes northeast and dips 45° to the southeast. This dolomite is bleached light grey and contains numerous cm-scale veins of white quartz and grey chert nodules.

North of the road, beginning at a point approximately 50 m northwest of the showing described above, a section of northeast-trending, interlayered dolomite, limestone and marble is sporadically exposed over a distance of 145 m. Within the steeply eastward-dipping sequence, at least 7 bands of white marble, ranging in width from 1 to 13 m, are present. The marble is fairly white and pure, and is intimately associated with cherty, quartz-veined dolomite. Repetitive bands of bluish limestone containing dolomitic burrows, mixed dolomite and marble are also present in the sequence.

Skidder Trail Deposit

White marble is exposed at several locations along the western margin of the White Arm Window. The showings occur within the Southern Arm Formation.

One of the marble showings, informally called the Skidder Trail deposit, is exposed discontinuously along the low ridges and logging trails about 500 m southwest of the Croque road. The deposit consists of interlayered white, high-

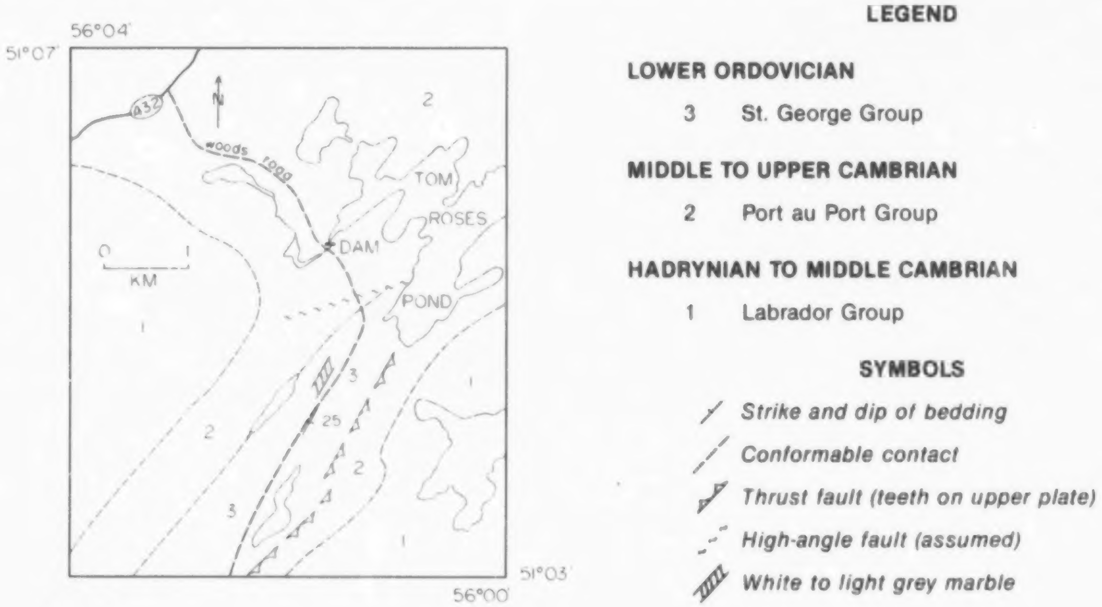


Figure 3. *Location of white marble deposit near Tom Roses Pond. Geology after Stouge (1983b).*

purity marble and beige-weathered, light-grey dolomite. Marble is the dominant rock unit in the deposit. Bands of marble, ranging in width up to 8 m, were observed along a northeast-trending belt traceable for more than 600 m. The marble is fine grained and somewhat chalky in places. Thin, silty laminations are found in some of the bands aligned along a strong cleavage that trends northeast and dips steeply (70°–80°) to the southeast.

It appears likely that significantly wider bands of marble than those noted exist in the area. It is difficult, however, to confirm this, because of lack of continuous outcrop. In one partially exposed section, the author collected chip samples over a 100-m width; only two minor bands of dolomite, (2-m and 4-m wide) were noted. Trenching and/or overburden drilling is necessary to properly assess the area.

Sawmill Deposits

White marble is exposed in two northeast-trending zones located approximately 3- and 4-km north of the Croque road (location C, Figure 2). Both lie within the Southern Arm Formation and outcrop along the flanks and crests of a series of northeast-trending low hills and ridges. A woods road, which branches northward from the Croque road, provides access to the area.

The southern zone consists of fine grained, white to grey marble bands interlayered with dolomite. The marble is strongly cleaved (020°/65°SE) and easily breaks into slabs. Lack of continuous outcrop makes it impossible to determine the maximum width of dolomite-free marble. However, separate discontinuous outcrops, 3- to 4-m wide, were observed and these were sampled over a sectional width of approximately 50 m. Impurities noted in the zone are sericite, iron stains along fracture planes, a chlorite schist band (1-m wide) and thin, cm-scale shaly bands.

The northern zone of marble showings consists of at least two bands of white marble, 15- and 20-m wide, located about 1 km north of the deposit described above. The marble outcrops along a low ridge. It is ivory white, fine- to medium-grained and strongly cleaved (020°/50°–55°SE).

The above marble occurrences suggest that there is excellent potential for locating significant deposits of white, high-purity marble in the White Arm Window. In particular, the area underlain by the Southern Arm Formation warrants more attention. Since bedrock exposure constitutes only about 5 percent of the area, trenching and/or overburden drilling is necessary to properly assess the marble potential of the region.

ST. GEORGE GROUP OUTSIDE OF WHITE ARM WINDOW

Geological Setting

Whitish-grey marble is present in a parauthochthonous slice of St. George Group limestone and dolomite located immediately south of Tom Roses Pond, approximately 4 km east of Route 432 (Figure 3). Stouge (1983b) assigned the host rocks to the Brent Island formation and attributed the marble to shearing and secondary bleaching of the unit.

Tom Roses Pond Deposit

The marble outcrops along a low ridge and also on a bush road joining Route 432 to the northwest corner of Coles Pond. It is fine- to medium-grained, strongly cleaved (025°/20°E),

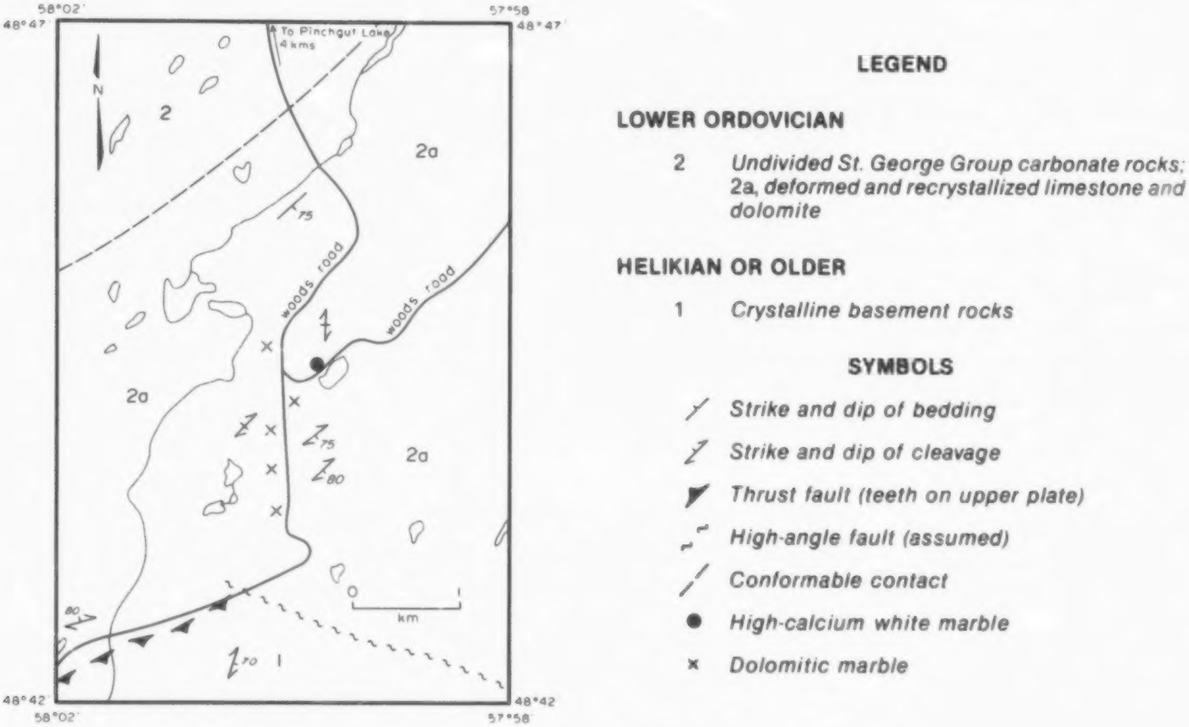

58°02'
48°47'
57°58
48°47'
To Pinchgut Lake
4 kms
N
2
2a
75
woods road
woods road
2a
75
80
2a
0
1
km
80
70
1
48°42'
58°02'
48°42
57°58'
LEGEND
LOWER ORDOVICIAN
2 Undivided St. George Group carbonate rocks; 2a, deformed and recrystallized limestone and dolomite
HELIKIAN OR OLDER
1 Crystalline basement rocks
SYMBOLS
Strike and dip of bedding
Strike and dip of cleavage
Thrust fault (teeth on upper plate)
High-angle fault (assumed)
Conformable contact
● High-calcium white marble
× Dolomitic marble

Figure 4. *Geological sketch map showing location of white marble and dolomitic marble south of Pinchgut Lake near Corner Brook. Geology after Williams (1981).*

and contains black and brown stains along fracture planes. In places, the marble has completely disintegrated into a white clay. The zone strikes northeast and is intermittently exposed for about 300 m. The thickness of this relatively flat-lying marble is unknown. Representative samples were collected for analyses.

CORNER BROOK AREA

Pinchgut Road Deposit

Narrow bands of ivory-white marble and wider, more extensive zones of pink dolomitic marble occur near Big Gull Pond about 20 km south of Corner Brook. A network of woods roads branching (south) from Pinchgut Lake on the Trans Canada Highway provides access to the area (Figure 4).

The white marble showings occur in highly deformed and recrystallized limestones and dolomites of the Lower Ordovician St. George Group. The best occurrence is 8 m wide; but because of overburden, it is traceable for only a few metres along strike. The marble is mottled dark grey on weathered surfaces and white on fresh surfaces; it has a slightly pink cast in some areas. It is fine- to medium-grained and has a strong, subvertical, north-trending cleavage. Other narrower bands of marble and some float were also observed in the immediate area. Representative samples were collected for chemical and physical analyses.

A 1500-m-wide zone of recrystallized dolomite and dolomitic marble, exposed by new road construction and located just south of the white marble, was also investigated and sampled. In places, the rock has an attractive red and pink colour, suggesting a potential use as building or decorative stone. However, the rock is extensively jointed and fractured and shatters easily. Impurities are small nodules of chert and pervasive hematite along fractures. Bands of recrystallized beige dolomite and mottled, blue-grey recrystallized dolomite also occur in the sequence.

ACKNOWLEDGMENTS

Dwayne Simms provided cheerful and competent help in the field. Crossing paths with Paul Delaney frequently resulted in useful discussions and advice as well as insights into the American League pennant race. The encouragement and advice from Paul Dean is also much appreciated. An early version of the manuscript was reviewed and improved by Sean O'Brien and Jamie Meyer.

REFERENCES

Howse, A.F.
1987: Marble assessment in the Roddickton area of the Great Northern Peninsula, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 145-149.

Knight, I.
1987: Geology of the Roddickton map area (12I/16). *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 343-357.

Smyth, W.R.
1971: Stratigraphy and structure of part of the Hare Bay Allochthon, Newfoundland. Geological Association of Canada Proceedings, Volume 24, pages 45-47.

Stouge, S.
1983a: Notes on the geology of the St. Julien's Map Area (2M/4), Great Northern Peninsula, Newfoundland (To accompany Map 82-68). Newfoundland Department of Mines and Energy, Mineral Development Division, 16 pages.

1983b: Notes on the geology of the Salmon River Map area (12P/1), Great Northern Peninsula, Newfoundland (To accompany Map 82-69). Newfoundland Department of Mines and Energy, Mineral Development Division, 11 pages.

Williams, H.
1981: Geological Map of the Stephenville map area, southwestern Newfoundland. Geological Survey of Canada, Open File 726.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 279-306

GOLD MINERALIZATION IN NEWFOUNDLAND: A 1988 REVIEW

J. Tuach, P.L. Dean, H.S. Swinden, C.F. O'Driscoll, B.F. Kean and D.T.W. Evans.
Mineral Deposits Section

ABSTRACT

This paper reviews the geological environments of gold mineralization in Newfoundland. Gold has been recovered as a by-product from volcanogenic massive sulphide deposits. Island-arc and ophiolitic environments of massive sulphide formation are documented and the deposits are intimately related to volcanic stratigraphy. These deposits will continue to be of major importance.

The economic potential of epigenetic deposits that occur as individual or multiple veins, stockworks, or replacement zones, is now being recognized. These deposits are the focus of most recent exploration efforts that include the Hope Brook, Cape Ray, and Mings Bight areas. They occur in a variety of secondary structural environments associated with major fault zones and lineaments. Epithermal alteration assemblages, commonly deformed by later fault movements, are widely developed in volcanic and sedimentary rocks varying in age from Late Hadrynian to Late Silurian, and extensive carbonatization occurs in and adjacent to ophiolitic ultramafic rocks. A spatial, possibly genetic, association between granites and gold is evident at some prospects, but is not a universal feature. Major fault and thrust fault zones enhanced and focussed fluid, and possibly some magmatic systems, and were the fundamental control over epigenetic mineralization.

INTRODUCTION

Volcanogenic massive sulphide deposits have traditionally been an important source of gold in Newfoundland with an approximate total production of 3 tonnes. The deposits were mined primarily for their base metals, but in some mines, gold contributed to the viability of mining and locally attained ore grades irrespective of the base-metal content.

The largest gold producers were deposits associated with felsic volcanic rocks at Buchans and at Rambler (Figure 2); other similar deposits also contain gold. The recent Duck Pond–Tally Pond discovery (Figure 2), and the identification of gold in the Rambler tailings, should ensure continued production from those types of deposits. Minor production has been achieved from ophiolite-related deposits and several of these are being investigated for their gold potential.

A substantial increase in exploration for epigenetic gold deposits in Newfoundland has taken place since 1984. Hope Brook Mine (Figure 6) commenced production in 1987 and is the province's first significant gold-only mine. Underground exploration has been conducted at Cape Ray and at Deer Cove (Figure 6), and major surface exploration projects are underway at numerous localities. These epigenetic deposits include single and multiple veins, silicified and replacement zones, and stockwork vein systems. They are characterized by a relatively low sulphide content when compared to volcanogenic massive sulphides, and represent an important resource to the province.

The new prospects occur predominantly in Paleozoic rocks of the Appalachian Orogen, although some are hosted by late Precambrian rocks. An extremely diversified depositional, structural, plutonic and tectonic history of the province provides an abundance of mineralized environments that collectively exhibit features common to gold deposits worldwide.

The objectives of this paper are to update an earlier summary of gold-bearing environments in Newfoundland (Dean *et al.*, 1985) and to present our perspective on the controls of gold mineralization in the province. The descriptive emphasis of the paper is on the setting of newly recognized epigenetic vein-type deposits. A summary of environments of deposition of massive sulphides is also given and this topic will be reviewed in greater detail in a later publication.

GEOLOGY OF NEWFOUNDLAND

Newfoundland occupies a central position in the Appalachian–Caledonian Orogen and lies at the northeastern edge of the Appalachian Orogen in North America (Williams, 1978). Three major tectonic-stratigraphic subdivisions are recognized (Figure 1), and the rocks record the evolution and destruction of the Lower Paleozoic Iapetus Ocean (Bird and Dewey, 1970; Williams, 1978, 1979; Williams and Hatcher, 1982).

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

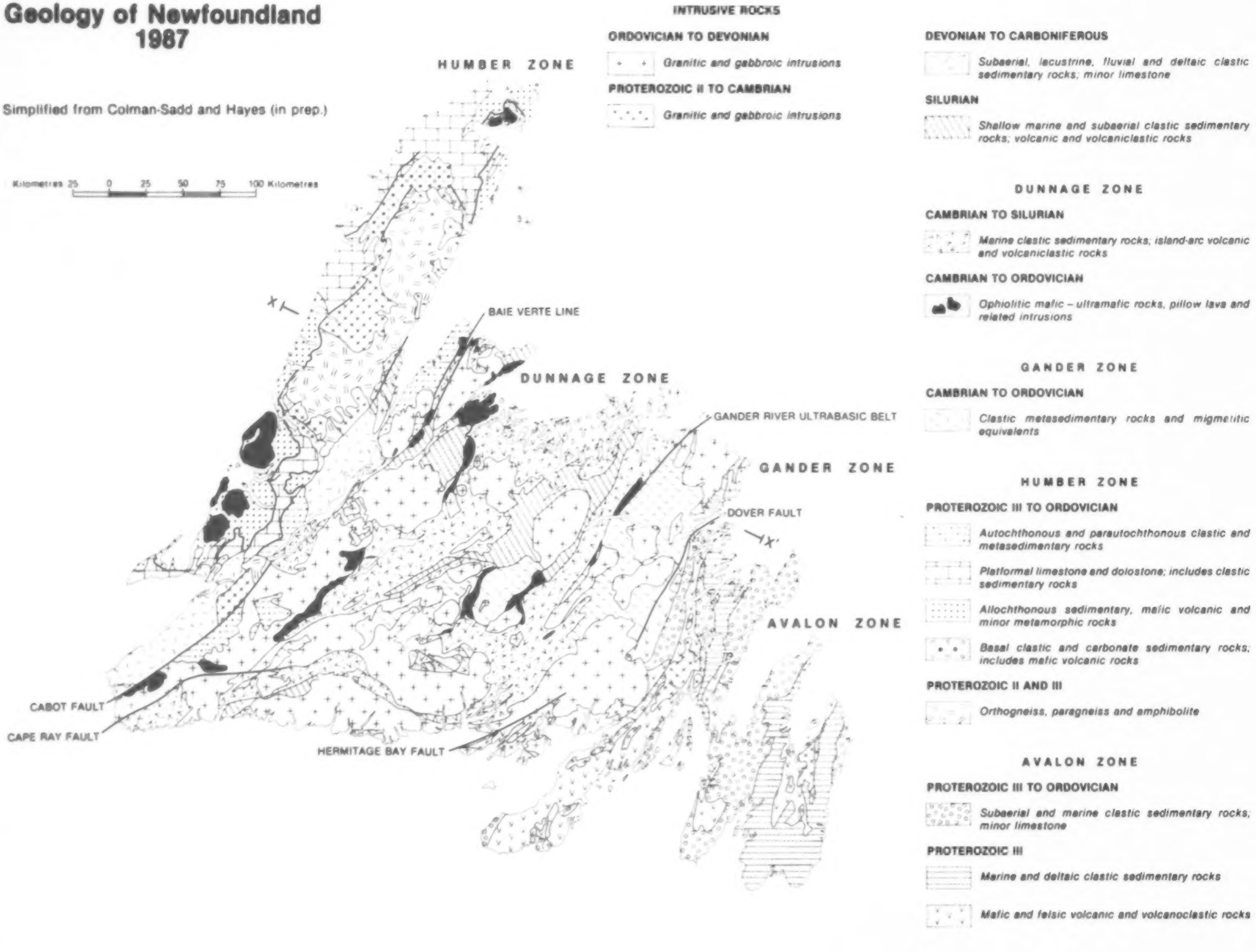

Geology of Newfoundland
1987
Simplified from Colman-Sadd and Hayes (in prep.)
Kilometres 25 0 25 50 75 100 Kilometres
HUMBER ZONE
DUNNAGE ZONE
GANDER ZONE
AVALON ZONE
BAIE VERTE LINE
GANDER RIVER ULTRABASIC BELT
DOVER FAULT
CABOT FAULT
CAPE RAY FAULT
HERMITAGE BAY FAULT
X
X'
INTRUSIVE ROCKS
ORDOVICIAN TO DEVONIAN
Granitic and gabbroic intrusions
PROTEROZOIC II TO CAMBRIAN
Granitic and gabbroic intrusions
DEVONIAN TO CARBONIFEROUS
Subaerial, lacustrine, fluvial and deltaic clastic sedimentary rocks; minor limestone
SILURIAN
Shallow marine and subaerial clastic sedimentary rocks; volcanic and volcaniclastic rocks
DUNNAGE ZONE
CAMBRIAN TO SILURIAN
Marine clastic sedimentary rocks; island-arc volcanic and volcaniclastic rocks
CAMBRIAN TO ORDOVICIAN
Ophiolitic mafic – ultramafic rocks, pillow lava and related intrusions
GANDER ZONE
CAMBRIAN TO ORDOVICIAN
Clastic metasedimentary rocks and migmatitic equivalents
HUMBER ZONE
PROTEROZOIC III TO ORDOVICIAN
Autochthonous and parautochthonous clastic and metasedimentary rocks
Platformal limestone and dolostone; includes clastic sedimentary rocks
Allochthonous sedimentary, mafic volcanic and minor metamorphic rocks
Basal clastic and carbonate sedimentary rocks; includes mafic volcanic rocks
PROTEROZOIC II AND III
Orthogneiss, paragneiss and amphibolite
AVALON ZONE
PROTEROZOIC III TO ORDOVICIAN
Subaerial and marine clastic sedimentary rocks; minor limestone
PROTEROZOIC III
Marine and deltaic clastic sedimentary rocks
Mafic and felsic volcanic and volcanoclastic rocks

Figure 1. *Generalized geology of Newfoundland. Prepared by J. Hayes from a preliminary version of a revised geological map of Newfoundland by S.P. Colman-Sadd and J. Hayes. X-X' shows position of section in Figure 22.*

The Humber Zone (also known as the Western Platform) consists of a platformal (miogeoclinal) sequence of Eocambrian to Ordovician quartzite, carbonate and shale above a basement of Late Grenvillian (ca. 1240 Ma, Erdmer, 1986) gneisses and plutonic rocks. Mafic dykes in the Grenvillian rocks may be related to an episode of crustal rifting that led to development of the Iapetus Ocean (Strong and Williams, 1972). Allochthonous sedimentary and ophiolitic sequences are also present in the Humber Zone.

The Avalon Zone consists of a platformal sequence of Eocambrian to Ordovician clastic sediments and carbonates deposited on Late Hadrynian metavolcanic, metasedimentary and plutonic rocks. The Hadrynian basement has been correlated with Pan-African sequences (O'Brien *et al.*, 1983), and may have developed during rifting to form the Iapetus Ocean, or during a pre-Iapetus cycle of ocean closing (Williams, 1979).

The Central Mobile Belt includes the Dunnage and Gander zones. It consists of lower Paleozoic, ocean margin clastic wedge deposits, ophiolite sequences, and island-arc/back-arc basin volcanic and sedimentary sequences. These rocks record the evolution and destruction of the Iapetus Ocean (Williams, 1978). Middle to late Paleozoic continental clastic and volcanic sequences are also well developed and were deposited after accretion of oceanic sequences to the North American Craton.

Early Ordovician deformation and metamorphism (locally to amphibolite facies) in the western part of the Central Mobile Belt, and locally on the Western Platform, record westward obduction of oceanic sedimentary and ophiolite rocks during the Taconic Orogeny (Williams and Stevens, 1974). Silurian and later, upright to recumbent folding, thrusting, and metamorphism (locally to amphibolite facies) of rocks in the Central Mobile Belt occurred dominantly during the Acadian Orogeny and record final closure of the Iapetus Ocean (Strong *et al.*, 1974; Colman-Sadd, 1980, Stockmal *et al.*, 1987). In the Avalon Zone, areas of deformation record a Late Hadrynian orogeny; Acadian structures are evident in the west and become weaker to the east. Late Devonian to Carboniferous deformation resulted from strike slip and vertical fault movements, and local brittle thrust faults (cf. Hyde, 1979; Blackwood, 1985).

Late Precambrian plutonism occurred in basement rocks of the Western Platform and Avalon Zone, and plutonism occurred throughout the Paleozoic history of the orogen (Strong, 1980; Hayes *et al.*, 1987). Eocambrian to Cambrian plutons having alkaline to peralkaline affinities in the Western Platform and in the Avalon Zone may have formed during rifting to form the Iapetus Ocean. Isolated lower Paleozoic trondjhemitic plutons occur in the Central Mobile Belt and in allochthonous ophiolitic rocks on the Western Platform; these may have formed in oceanic crust or in the roots of oceanic island arcs. Large areas of Middle Ordovician granodiorite and tonalite occur along the western margin of the Central Mobile Belt. Major granitic plutonism occurred in the Middle Silurian to Early Devonian during the final stages of closure of the Iapetus Ocean. A variety of pluton types represent different tectonic environments; for example, calc-alkaline plutons with I-type affinities may be subduction related, whereas peraluminous granitoids with S-type affinities may be crustal melting during collision, and metaluminous to peralkaline plutons in the western part of the Central Mobile Belt may represent an anorogenic epicontinental setting (Coyle and Strong, 1987). Upper Devonian to Carboniferous metaluminous granites with A-type affinites occur throughout the eastern part of the Central Mobile Belt and in the Avalon Zone and cut many of the earlier structures.

MASSIVE SULPHIDE DEPOSITS

Gold has been produced from the base-metal mines developed in volcanogenic massive sulphide deposits in lower Paleozoic volcanic and volcaniclastic sequences (Figure 2; Table 1). Most of the production has been from exhalative, syngenetic massive sulphides although minor amounts have also been recovered from related stockwork zones.

Two main subdivisions of auriferous massive sulphide deposits are recognized in Newfoundland (cf. Swinden and Thorpe, 1984; Swinden and Kean, 1984, *in press*): 1) deposits associated with felsic volcanic rocks in mafic-felsic sequences and 2) deposits associated with pillow lavas of ophiolite sequences. A third type of massive sulphide deposit recognized by Swinden and Kean *(in press)* occurs in non-ophiolitic mafic volcanic rocks (the Fox Neck-type, which may also include the Great Burnt Lake deposit) but is not known to contain anomalous gold.

Deposits in Mafic–Felsic Sequences

The base- and precious-metal contents of massive sulphide deposits in mafic–felsic arc volcanic sequences in the Central Mobile Belt reflect regional variations in the compositions of the underlying volcanic rocks (Swinden and Thorpe, 1984; Swinden and Kean, 1984, *in press*). Three broad categories are recognized based on the relative amount of mafic and felsic rocks within the volcanic–volcaniclastic sequences (Figures 2, 3, 4).

Massive sulphide deposits in mafic-dominated sequences are copper- and/or zinc-rich (Figure 4a); those in the mixed sequences are polymetallic (Cu, Zn, Pb) and those in felsic-dominated sequences are zinc and lead rich. This is interpreted to reflect the availability of the metals to the hydrothermal cells during leaching, with Cu and Zn having been more abundant in the mafic volcanic rocks and Pb in felsic rocks. Similarly, the relative precious-metal contents of the various deposits is apparently a function of the composition of the host volcanic sequence (Figure 4b). Deposits hosted by mafic-dominated sequences generally have the highest gold/silver ratios and this ratio decreases with increasing proportions of felsic volcanic rocks in the underlying stratigraphic section. Irrespective of metal ratios, the absolute concentration of gold in any particular deposit is a function of the size of the hydrothermal system and the physicochemical conditions at the site of deposition.

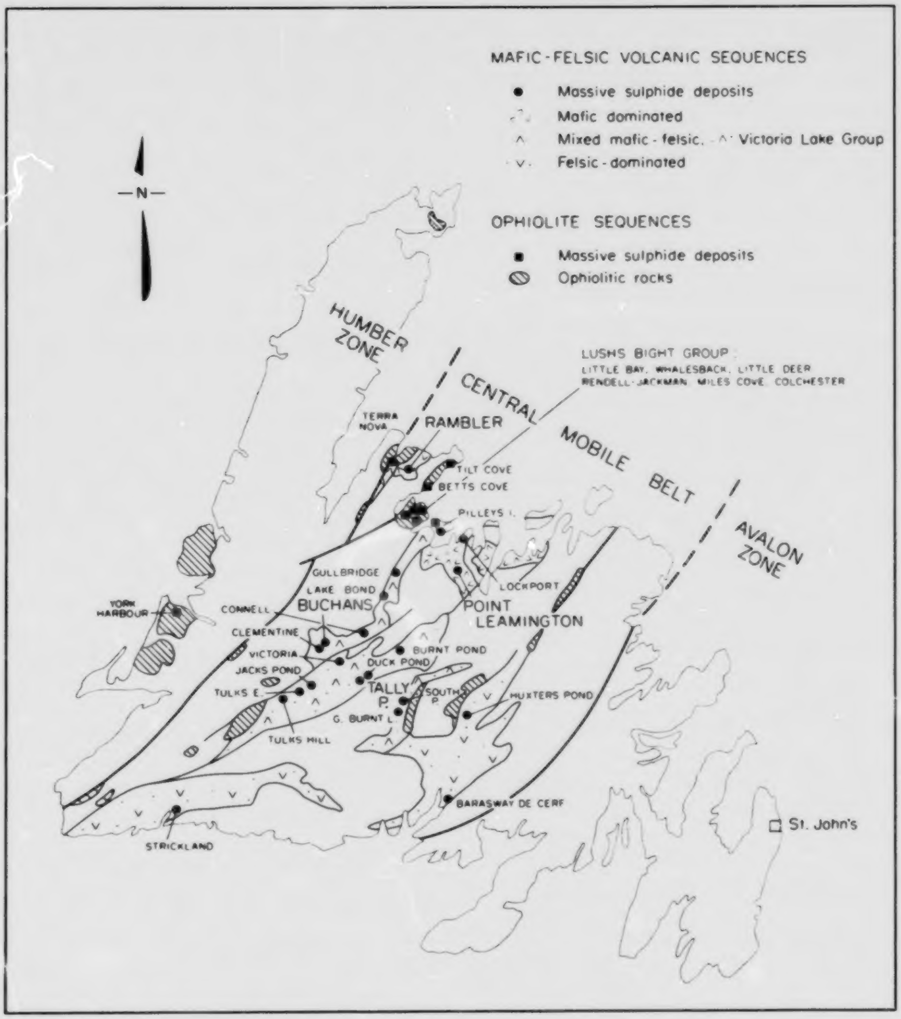

MAFIC-FELSIC VOLCANIC SEQUENCES
● Massive sulphide deposits
Mafic dominated
^ Mixed mafic-felsic, ^ Victoria Lake Group
v Felsic-dominated
OPHIOLITE SEQUENCES
■ Massive sulphide deposits
Ophiolitic rocks
N
HUMBER ZONE
CENTRAL MOBILE BELT
AVALON ZONE
LUSHS BIGHT GROUP:
LITTLE BAY, WHALESBACK, LITTLE DEER
RENDELL-JACKMAN, MILES COVE, COLCHESTER
TERRA NOVA
RAMBLER
TILT COVE
BETTS COVE
PILLEYS I.
GULLBRIDGE
LAKE BOND
LOCKPORT
YORK HARBOUR
CONNELL
BUCHANS
POINT LEAMINGTON
CLEMENTINE
BURNT POND
VICTORIA
DUCK POND
JACKS POND
TULKS E.
TALLY P.
SOUTH P.
HUXTERS POND
G. BURNT L.
TULKS HILL
BARASWAY DE CERF
STRICKLAND
St. John's

Figure 2. *Location of lower Paleozoic volcanogenic massive sulphide deposits and classification of the host sequences in Newfoundland.*

Economic concentrations of gold may accumulate in any environment where suitable source rocks are present.

The gold content of individual massive sulphide deposits may be relatively consistent between ore deposits in a deposit cluster as at Buchans (Thurlow and Swanson, 1981; Kirkham, 1987), or may vary between deposits as at Rambler (an average of 5.1 g/t gold was produced from the Main Mine; Table 1; Tuach and Kennedy, 1978). Significant variation can also occur within a single massive sulphide deposit as at Point Leamington (D. MacInnis, personal communication, 1987).

Deposits in Ophiolite Sequences

These are the most common type of volcanogenic sulphide deposits in Newfoundland (Table 1; Figure 2). They are copper- and zinc-rich and occur at all stratigraphic levels (Figure 5) within the ophiolitic pillow lava sequences (Duke and Hutchison, 1974; Kean, 1983; Kean, 1984). For example, the Betts Cove deposits occur at the base of the pillow lavas immediately above the sheeted-dike horizon (Uphadhyay and Strong, 1973), the York Harbour deposits occur in pillow lavas well above the sheeted dykes, and the Timber Pond deposit occurs at the top of the pillow lavas (Kean and Evans, *this volume).* It is also possible that deposits of the East Mine at Tilt Cove were formed at the top of the pillow lavas (although for an alternate viewpoint, see Strong, 1984). Several of the deposits occur in chlorite schist zones (e.g., Little Bay, Whalesback) related to shears preferentially developed along syngenetic alteration zones in mafic volcanic rocks and dykes (Kean, 1984).

Gold/silver ratios in these deposits are high (Figure 4), probably relecting the mafic (and potentially ultramafic) composition of the available source rocks. The gold content of the deposits has not been well documented, and production,

Table 1. Base- and precious-metal contents of selected volcanogenic massive sulphide deposits in Newfoundland

Deposit Name	Production/Reserves (Tonnes)		Grade					Gold Production	Comments
			Cu%	Pb%	Zn%	Ag(g/t)	Au(g/t)		
FELSIC DOMINATED									
Strickland	260,000			5.25%		195	S		
Barasway de Cerf				-		-	-		
MAFIC/FELSIC									
Victoria Mine	200,000	R	7.5*	1.5	2.4	12	0.14		*Assay of grab sample from dump Tonnage is approximate
Tulks Hill	750,000	R	1.3	2	5-6	41	0.4		
Tulks East	A. 4,500,000	R	0.24	0.12	1.5	8.5	tr		
	B. 200,000	R	0.66	1.26	8.69	58.7	0.14		
	C. 900,000	R	<1% combined Cu + Pb + Zn						
Jacks Pond	200,000 to 900,000	R	Not reported but generally low						4 lenses
Boundary	500,000	R	3.5	1	4	34	S		
Duck Pond	3,600,000	R	3.71	1.36	7.58	72.3	1.2		
Burnt Pond	?		-	-	-	-	-		
Pilley's Island	1,051,436	P	1.23	-	-	-	S		
Lake Bond	1,096,699	R	0.31	-	2.12	-	S		
Gullbridge	3,466,000	P	1.02	-	-	-	-		
Southwest Shaft	<90,000	R	1-2	-	-	-	S		
Buchans	16,196,876	P	1.33	7.56	14.51	126	1.37	P 22,000 kg	
Connell Option	?		0.3	11.9	25.4	158	3.4		1 DDH
Clementine	363,000	R	0.3	2.6	4.9	10.3	S		
Great Burnt Lake	750,000	R	2.9	-	-	-	S		
South Pond	270,000	R	1.3	-	-	-	1.37		
MAFIC DOMINATED									
Rambler	399,000	P	1.3	-	2.16	29	5.1		
Ming	1,991,592	P	3.66	-	-	22	2.4	P 5,400 kg	
East	1,993,079	P	1.04	-	-	-	-		
Big Rambler Pond	45,000	P	1.2	-	-	-	-		Selected sample 1.4 g/t
Mine Tailings	2,000,000	R	?	?	?	?	1.6		Very approximate
Point Leamington	18,000,000	R	0.5	-	2	-	1.0		
Lockport	555,000	R	0.75	-	-	-	S		
OPHIOLITE-HOSTED(%)									
Skidder	900,000	R	2	-	2	-	-		
Tilt Cove	8,163,000	P	1-12	-	-	-	-	P <1,500 kg	
Betts Cove	118,528	P	2-10	-	-	-	-		
Terra Nova	226,750	P	2-2.5	-	-	-	1.6		dump sample; 16.8 g/t
Little Bay	3,083,800	P	.8-2	-	-	-	-	P 195 kg	
Whalesback	3,792,809	P	.85-1.1	-	-	-	?		
Little Deer	392,000	P & R	1.5	-	1.5	-	S		
Miles Cove	200,000	R	1.45	-	-	12	0.34		
Rendell-Jackman	10,000	R	1-5	-	-	-	1 g/t		
Colchester	1,000,000	R	1.3	-	-	-	S		
McNeily	-	R	.5-4	-	-	-	-		Grabs to 4 g/t
York Harbour	300,000	P & R	1.9	-	4.7	-	-	M 5 kg	

S – Sporadic (<0.4 g/t)   P – Produced   M – Mined   R – Reserves (geological)   tr – trace

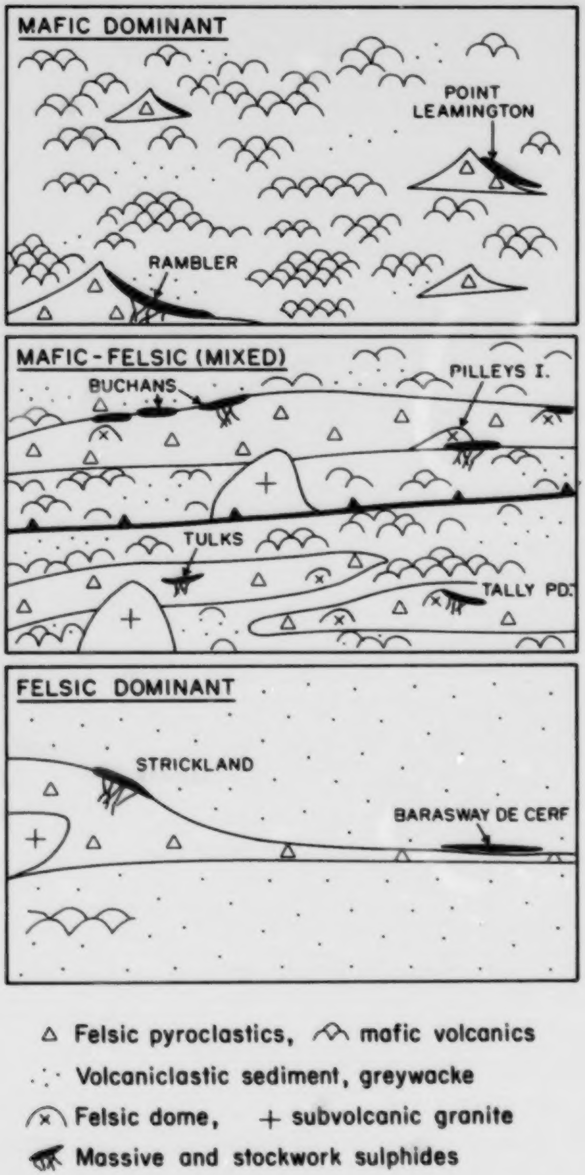

MAFIC DOMINANT
POINT LEAMINGTON
RAMBLER
MAFIC-FELSIC (MIXED)
BUCHANS
PILLEYS I.
TULKS
TALLY PD.
FELSIC DOMINANT
STRICKLAND
BARASWAY DE CERF
Felsic pyroclastics, mafic volcanics
Volcaniclastic sediment, greywacke
Felsic dome, + subvolcanic granite
Massive and stockwork sulphides

Figure 3. *Schematic diagram showing stratigraphic setting of massive sulphide deposits in mafic–felsic sequences in central Newfoundland.*

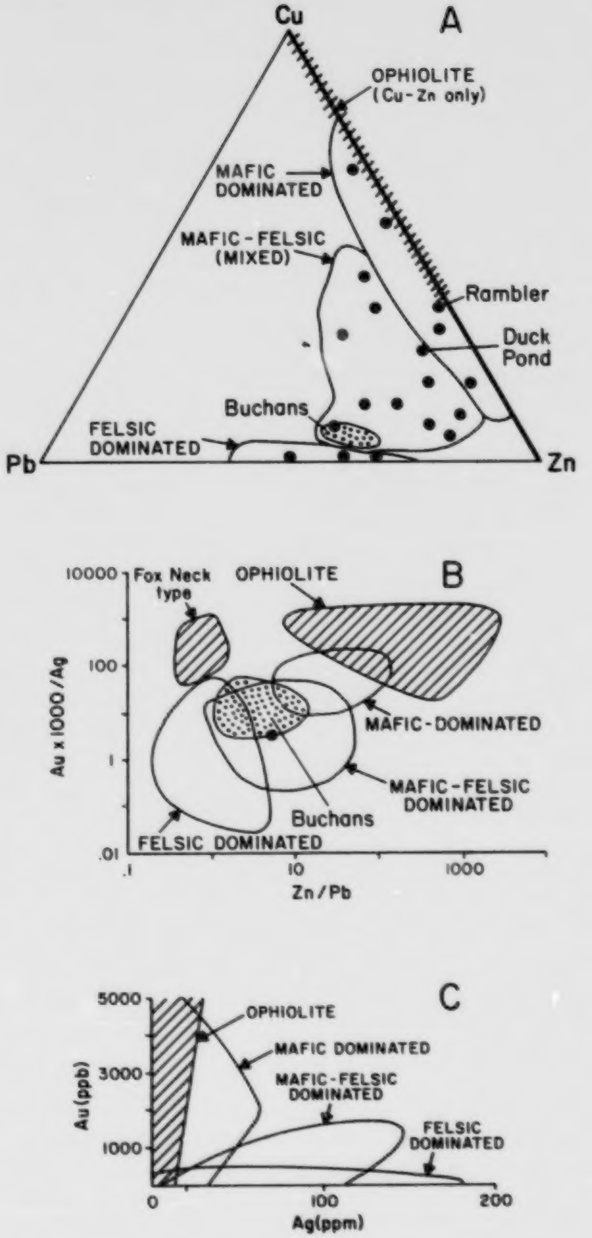


Figure 4. *(A) Cu-Pb-Zn, (B) Au/Ag-Zn/Pb and (C) Au-Ag ratios in massive volcanogenic sulphide deposits in Newfoundland. From unpublished analyses of dump samples and data compiled by S. Swinden and B.F. Kean.*

which mainly occurred prior to 1970, has been minor (Table 1). This may in part be a function of primitive analytical techniques and poor recovery. All the deposits were mined (or delineated) for copper; zinc from sphalerite, which is locally abundant, was not generally recovered. Recent data suggests that gold in these deposits is associated with sphalerite (Hurley and Crocket, 1985; Kean, unpublished data), and would have been therefore discarded during mining. Values in excess of 1 g/t gold were obtained from assays of dump material at Betts Cove (Saunders, 1985), York Harbour, Tilt Cove, and deposits throughout the Lushs Bight Group (Kean, unpublished data; Tuach, 1987a). In addition, ore-grade material is reported in outcrop at Tilt Cove (Kusmirski and Norman, 1982).

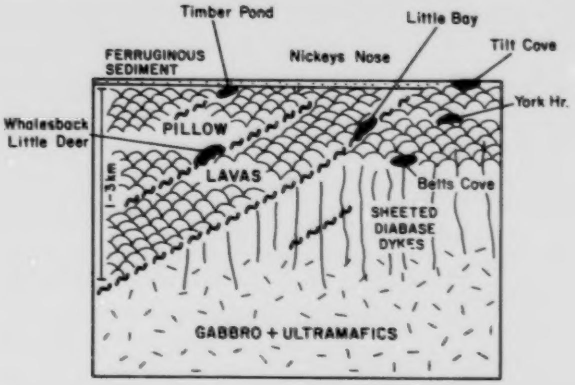


Figure 5. *Schematic diagram showing stratigraphic and structural setting of massive sulphide deposits in ophiolitic rocks in Newfoundland. These deposits occur in several different ophiolite sequences.*

Paleotectonic Environments of Massive Sulphide Formation

The thick mafic–felsic volcanic sequences in the Central Mobile Belt have been generally considered to record volcanism and mineralization in an island-arc environment (Mitchell and Garson, 1976; Swinden and Strong, 1976). Recent detailed geochemical studies in some sequences, for example, the Wild Bight Group (Swinden, 1987), the Victoria Lake Group, (Swinden and Kean, unpublished data), and the Buchans Group (Thurlow, 1973; Swinden, unpublished data) confirm these interpretations. In the Wild Bight Group, it has been suggested that mineralization occurred during rifting of an island arc prior to opening of a Middle Ordovician back-arc basin (Swinden, 1987).

The ophiolitic sequences are considered generally to record active rifting in back-arc environments (e.g., Dunning and Krogh, 1985), although some such as the Betts Cove Complex (Coish *et al.*, 1982) and the Lushs Bight Group (B.F. Kean and G.A. Jenner, unpublished data) contain geochemical evidence of the proximity of a subducting slab. In fact, the boundaries between the environments recorded by the two types of sequences may not be sharp. For example, the Rambler deposits (Figure 2) are associated with mafic and felsic volcanic rocks of the Pacquet Harbour Group which have been previously interpreted as representing an immature island-arc environment (e.g., Hutchinson, 1973; Tuach and Kennedy, 1978; Dean, 1978). Hibbard (1983), however, correlated magnesian volcanic rocks in the Pacquet Harbour Group with those in the Betts Cove complex, implying that the ore-bearing strata were actually part of a fragmented ophiolite (see also Gale, 1973). The latter interpretation is supported by recent unpublished geochemical data (G.A. Jenner, personal communication, 1987). The implication is that the ophiolites may have been generated in a suprasubduction zone environment. Clearly, there are ambiguities in the present classification that need to be resolved. In any event, the high heat flow associated with events in the island-arc or back-arc environments probably determine whether metal-rich hydrothermal systems develop.

The Fox Neck-type deposits apparently formed in back-arc settings not associated with active rifting (Swinden and Kean, *in press*). The deposits are generally metal-poor and it seems that although the hydrothermal systems were probably circulating in good Cu-, Zn- and Au-source rocks (i.e., oceanic crust), these metals were not transported to the ore-forming environment. It is suggested that these hydrothermal systems were generally small and short lived and not always capable of carrying significant quantities of most metals. They may have been the remnants of previously active systems which had drifted away from the main centers of tectonic activity and high heat flow, or they may have been associated with areas of low heat flow within the back arcs, such as along transform faults.

EPIGENETIC DEPOSITS

Geological descriptions of epigenetic gold mineralization (Figure 6) in the main areas of active exploration are presented below. They illustrate the variety of styles and environments of gold mineralization encountered in Newfoundland. The deposits include individual and multiple vein systems, stockworks, silicified zones, and replacement zones that are of epigentic origin. They are characterized by a relatively low to minor sulphide content when compared to syngenetic volcanogenic massive sulphide deposits. The mineralization and alteration in each area is described, and placed in the context of popular models of gold mineralization. The genetic inferences will no doubt expand and change as further information becomes available, particularly in central and southern Newfoundland where interpretation is difficult because of regional tectonic overprinting and multiple deformation along major fault zones.

Avalon

The Hickey's Pond Prospect (Table 2) is located on the Burin Peninsula in an 80-km-long zone of high-alumina and silica alteration that extends from Hickey's Pond to the Knee (Figure 7). The zone contains pyrophyllite, alunite, sericite, specularite, lazulite, chloritoid, apatite, rutile, and pyrite (Huard and O'Driscoll, 1985, 1986). The prospect is hosted by banded and hydrothermally brecciated hematite- and alunite-bearing rocks in a zone of advanced argillic alteration in Hadrynian volcanic rocks of the Love Cove Group (Figure 8). The deposit is separated from the Late Hadrynian Swift Current Granite by a fault. The alteration zone and the surrounding rocks exhibit a penetrative tectonic fabric and a low-greenschist-facies metamorphic assemblage.

The alteration assemblages and depositional features at Hickey's Pond led Huard and O'Driscoll (1986) to conclude that the deposit formed in an epithermal–fumarolic environment. Deposits throughout the belt vary from sinters and chemical precipitates with geyserite eggs to deeper-level hydrothermal stockworks and breccias. Pervasively altered volcanic rocks are ubiquitous.

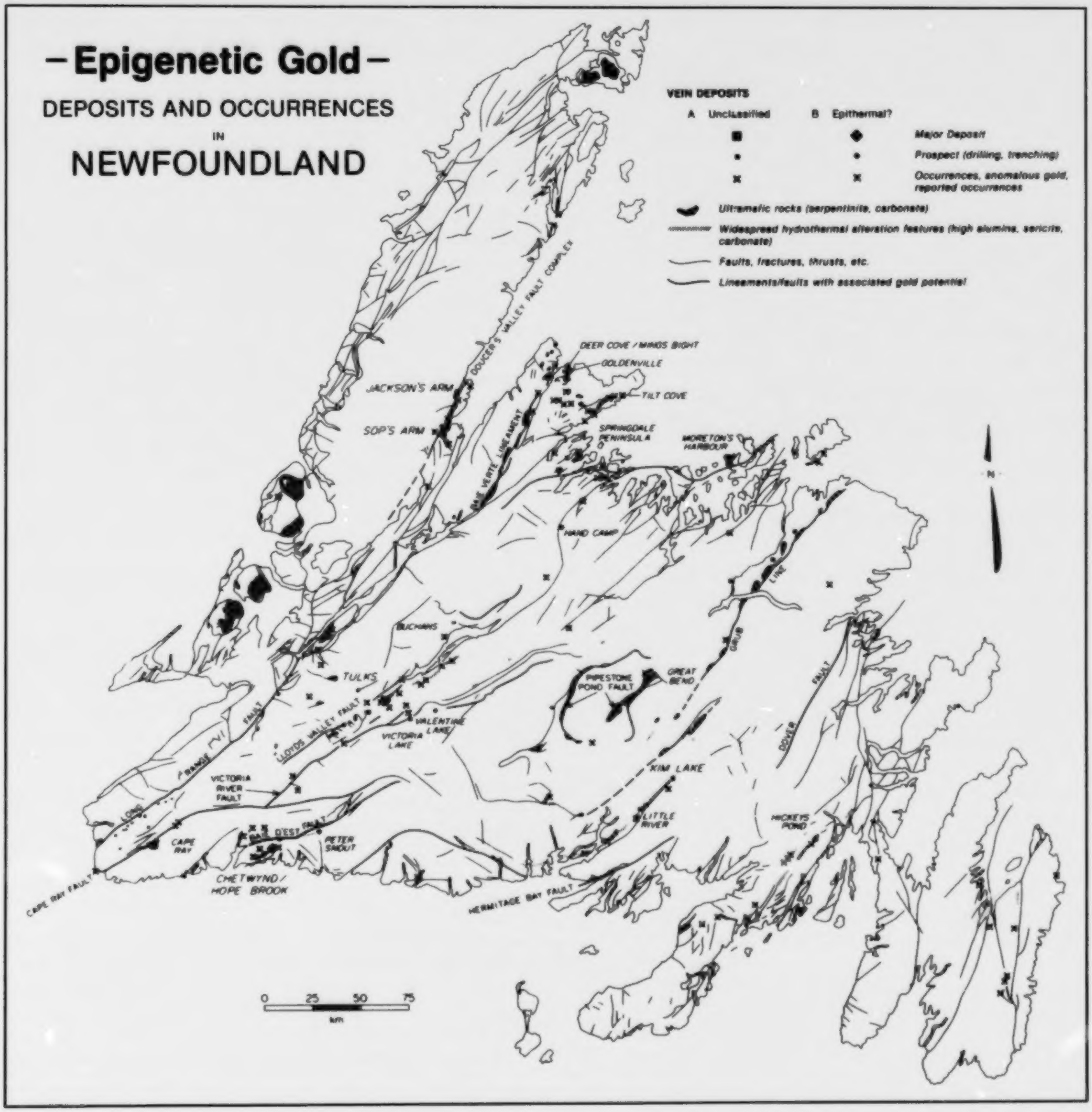

-Epigenetic Gold-
DEPOSITS AND OCCURRENCES
IN
NEWFOUNDLAND
VEIN DEPOSITS
A Unclassified
B Epithermal?
Major Deposit
Prospect (drilling, trenching)
Occurrences, anomalous gold, reported occurrences
Ultramafic rocks (serpentinite, carbonate)
Widespread hydrothermal alteration features (high alumina, sericite, carbonate)
Faults, fractures, thrusts, etc.
Lineaments/faults with associated gold potential
DOUCERS VALLEY FAULT COMPLEX
DEER COVE / MINGS BIGHT
GOLDENVILLE
TILT COVE
JACKSON'S ARM
SOP'S ARM
BAIE VERTE LINEAMENT
SPRINGDALE PENINSULA
MORETON'S HARBOUR
HAND CAMP
N
BUCHANS
GRUB LINE
TULKS
GREAT BEND
PIPESTONE POND FAULT
LLOYDS VALLEY FAULT
VALENTINE LAKE
VICTORIA LAKE
DOVER FAULT
RANGE FAULT
VICTORIA RIVER FAULT
KIM LAKE
LONG RANGE
CAPE RAY
BAIE D'EST FAULT
PETER SNOUT
LITTLE RIVER
HICKEYS POND
CAPE RAY FAULT
CHETWYND/ HOPE BROOK
HERMITAGE BAY FAULT
0 25 50 75
km

Figure 6. *Distribution of reported epigenetic gold deposits and occurrences in Newfoundland showing preliminary classification. Structures are shown, together with the location of ultramafic rocks and areas of extensive hydrothermal alteration. Structures with associated gold mineralization are highlighted. Simplified from Tuach (1987a).*

Minor gold occurrences in similar geological settings are found along the belt at Monkstown road (Figure 8) and at the Knee (Figure 7). Other areas of silica-sericite-pyrite alteration and anomalous gold content (i.e., > 0.4 g/t Au) have also been reported from other parts of the Avalon Zone (Figure 7; Tuach, 1987a; S. O'Brien 1987). A 7-km-long zone of high-alumina alteration (but no reported gold values) also occurs at and south of the Foxtrap Pyrophyllite Mine (Figure 7). The alteration is hosted by felsic volcanic rocks of the Late Hadrynian Harbour Main Group near the contact with the Late Hadrynian Holyrood Granite. The ore zone consists of massive and schistose pyrophyllite. Large areas of pervasive silica and sericite alteration are associated with the deposit and minor kaolinite, diaspore, specularite, pyrite, and rutile are present. Spectacular hydrothermal breccias are developed at and adjacent to the Foxtrap Mine. Conglomerate overlying

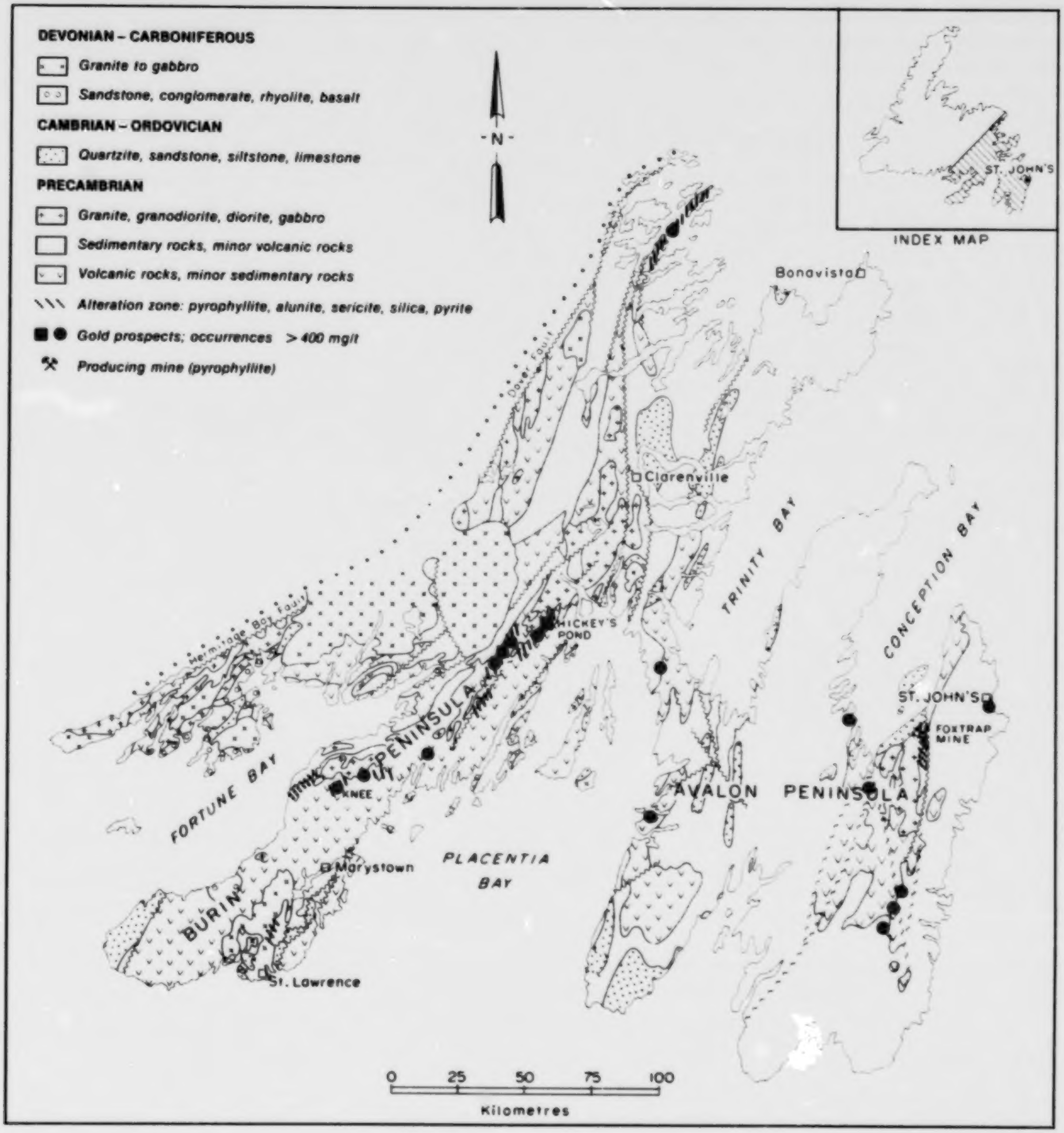

DEVONIAN – CARBONIFEROUS
Granite to gabbro
Sandstone, conglomerate, rhyolite, basalt
CAMBRIAN – ORDOVICIAN
Quartzite, sandstone, siltstone, limestone
PRECAMBRIAN
Granite, granodiorite, diorite, gabbro
Sedimentary rocks, minor volcanic rocks
Volcanic rocks, minor sedimentary rocks
Alteration zone: pyrophyllite, alunite, sericite, silica, pyrite
Gold prospects; occurrences >400 mg/t
Producing mine (pyrophyllite)
N
INDEX MAP
ST. JOHN'S
Bonavista
Dover Fault
Clarenville
TRINITY BAY
CONCEPTION BAY
Hermitage Bay Fault
HICKEY'S POND
PENINSULA
ST. JOHN'S
FOXTRAP MINE
AVALON PENINSULA
FORTUNE BAY
KNEE
Marystown
PLACENTIA BAY
BURIN
St. Lawrence
0
25
50
75
100
Kilometres

Figure 7. *Simplified geology and epigenetic gold occurrences in the Avalon Zone. Areas of extensive pyrophyllite-sericite-alunite-silica alteration are shown.*

the pyrophyllite zone contains both altered and unaltered volcanic fragments and is locally pervasively altered. The field relationships indicate that the alteration zone grew through a rapidly accumulating debris-fan adjacent to a fault scarp.

The rocks in the Foxtrap area are unconformably overlain by Lower Cambrian conglomerate, therefore, a Late Hadrynian age for development of the alteration is indicated. This alteration probably occurred in a high-level epithermal system (cf. Berger and Eimon, 1983; Figure 9) related to

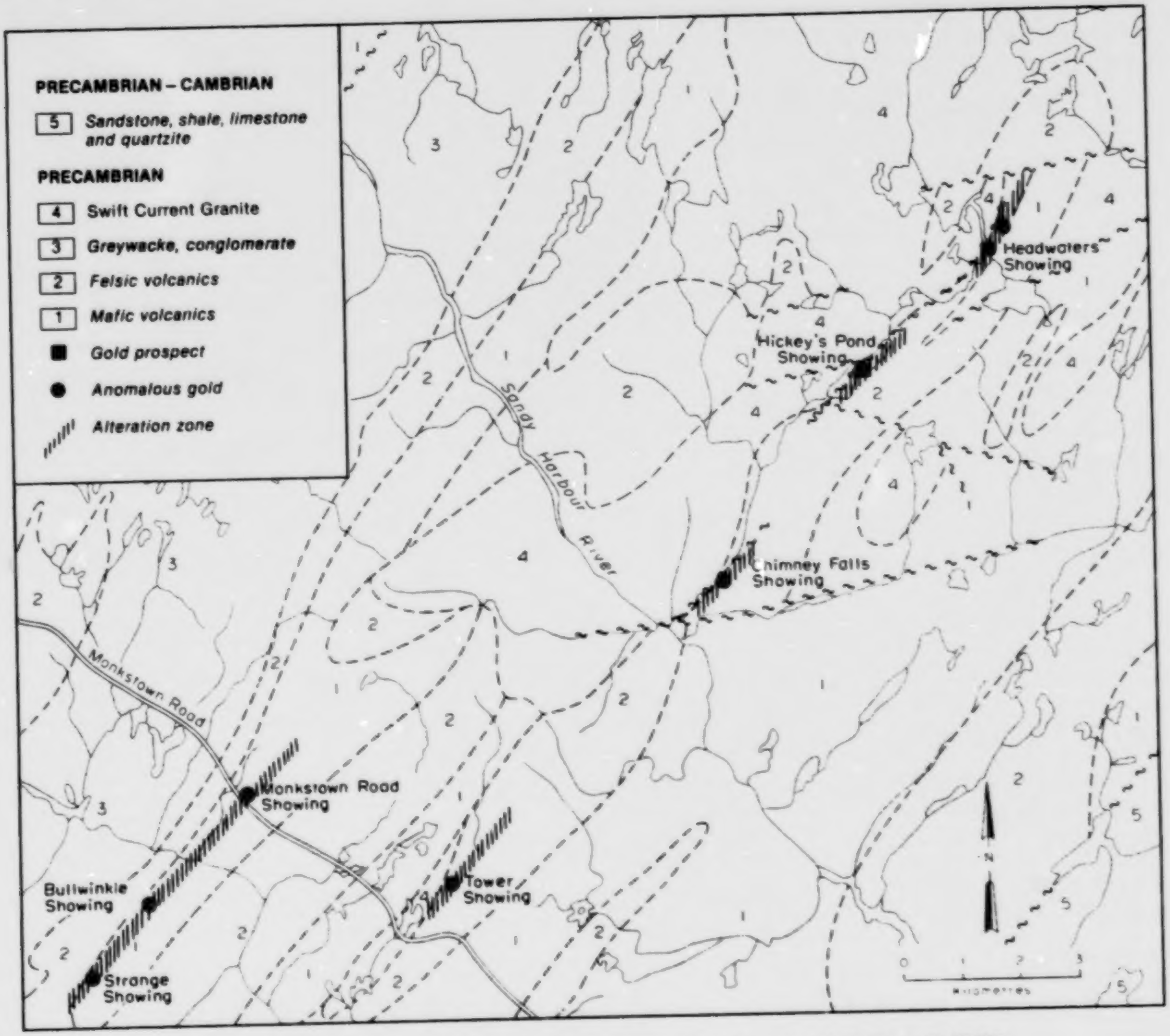

PRECAMBRIAN – CAMBRIAN
5 Sandstone, shale, limestone and quartzite
PRECAMBRIAN
4 Swift Current Granite
3 Greywacke, conglomerate
2 Felsic volcanics
1 Mafic volcanics
■ Gold prospect
● Anomalous gold
Alteration zone
Headwaters Showing
Hickey's Pond Showing
Sandy Harbour River
Chimney Falls Showing
Monkstown Road
Monkstown Road Showing
Bullwinkle Showing
Tower Showing
Strange Showing
N
0
1
2
3
Kilometres

Figure 8. *Geology of the Hickey's Pond prospect; from Huard and O'Driscoll (1986).*

Table 2. Gold in epigenetic deposits in Newfoundland

Major Deposit	Million Tonnes	Grade g/t Au	Comments
Hope Brook	11.2	4.54	Minor Cu
Main Zone/Cape Ray	0.9	5.75	Zn, Pb, Cu, Ag

Prospects/Major Projects	Best Result g/t Au	Comments
Apsy Zone/Jackson's Arm	DDH: 2.27 g/t over 10 m	
Road Zone/Jackson's Arm	DDH: 1.23 g/t over 54.5 m	
Browning/Sops Arm		4.6 kg Au produced
Unknown Brook/Sops Arm	DDH: 8.4 g/t over 1.75 m	
Deer Cove/Mings Bight	ADIT: 16.1 g/t across 1.5 m over 30 m	
Bradley/Mings Bight	TRENCH: 6.3 g/t over 14 m	
Goldenville/Mings Bight		4.6 kg Au produced
Windowglass Hill/Cape Ray	DDH: 4.6 g/t over 12.5 m	
Mine Pond	DDH: 8.2 g/t over 1.5 m	
Hand Camp	DDH: 10.6 g/t over 3.0 m	
Midas Pond/Victoria	NA	
Valentine Lake/Victoria	NA	
Little River	DDH: 3.8 g/t over 4.0 m	
Hickeys Pond	DDH: 0.59 g/t over 1.5 m	Grab: 2.5 to 5.4 g/t

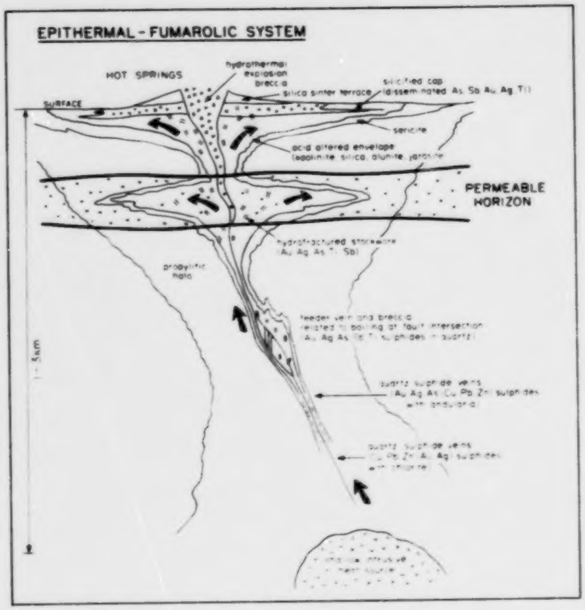

EPITHERMAL - FUMAROLIC SYSTEM
HOT SPRINGS
hydrothermal explosion breccia
silicified cap (disseminated As, Sb, Au, Ag, Tl)
silica sinter terrace
SURFACE
sericite
acid altered envelope (kaolinite, silica, alunite, jarosite)
PERMEABLE HORIZON
hydrofractured stockwork (Au, Ag, As, Tl, Sb)
propylitic halo
feeder vein and breccia related to boiling at fault intersection (Au, Ag, As, (Sb, Tl) sulphides in quartz)
1 - 5km
quartz sulphide veins (Au, Ag, As (Cu, Pb, Zn) sulphides with adularia)
quartz sulphide veins (Cu, Pb, Zn (Au, Ag) sulphides with chlorite)
intrusive heat source

Figure 9. *Epithermal–fumarolic model for silver–gold mineralization; from Berger and Eimon (1983).*

intrusion of the Holyrood Granite (Papezik *et al.*, 1976; O'Driscoll and Tuach, 1987).

These Late Hadrynian epithermal–fumarolic systems correlate with similar, gold-bearing, Late Hadrynian environments in the Carolina Slate Belt of the southeastern United States (Spence *et al.*, 1980; Schmidt, 1983). The systems indicate extensive high-level alteration and local gold mineralization in the waning stages of volcanism during an early stage, or possibly prior to, development of the Appalachian Orogen.

Little River–Kim Lake

Gold is present in a variety of rocks of the Ordovician Baie d'Espoir Group (Figure 10). The gold is associated generally with fine grained, disseminated stibnite and arsenopyrite and locally with heavily mineralized stibnite-bearing veins and veinlets. Most of the prospects have been severely tectonized.

In the Kim Lake Prospect, historically regarded as a stibnite prospect (e.g., Swinden, 1981), gold occurs in thin, anastomosing quartz veins hosted by carbonatized rhyolite and/or porphyritic felsic intrusive rocks. At the Little River Prospect (McHale, 1985), gold is associated with a steeply dipping, silicified and mylonitized zone (up to 2 m wide and 4 km long) containing stockworks of quartz–carbonate veins and veinlets in silicic tuff. Gold in the Le Pouvoir horizon is associated with disseminated sulphides in fine grained chloritic schist. Other prospects in the area are hosted by laminated graphitic sediments, mafic tuffs, and carbonatized diabase and gabbro (McHale, 1985).

Carbonatization of the various rock types is the most distinctive alteration feature. Linear zones of silicification are also reported, and areas of sericite alteration are widespread. A band of quartz veining with minor pyrophyllite, specularite, and locally dumortierite and minor lazulite occurs along the Collins Brook Fault (Figure 10). Collectively, these alteration features indicate a variety of deep- to shallow-level mineralizing events. The linear and apparently conformable zones of alteration and mineralization at Little River and Le Pouvoir were interpreted to represent exhalative or syngenetic mineralization by McHale (1985) and McHale and McKillen (1986).

Recent mapping to the north of the Little River Prospect by Dickson *(this volume)* has identified a small outcrop of magnesite that probably represents a slice of carbonatized ultramafic rock. The outcrop is interpreted to mark the trace of a major fault called Le Pouvoir Fault (Figure 10) and the northward extension of the Day Cove Thrust lies approximately 2 km east of the Le Pouvoir Fault. These features suggest that the gold mineralization may be related to imbricate faulting and thrusting in the Little River area, an observation supported by the presence of mylonitic textures in the Little River Prospect.

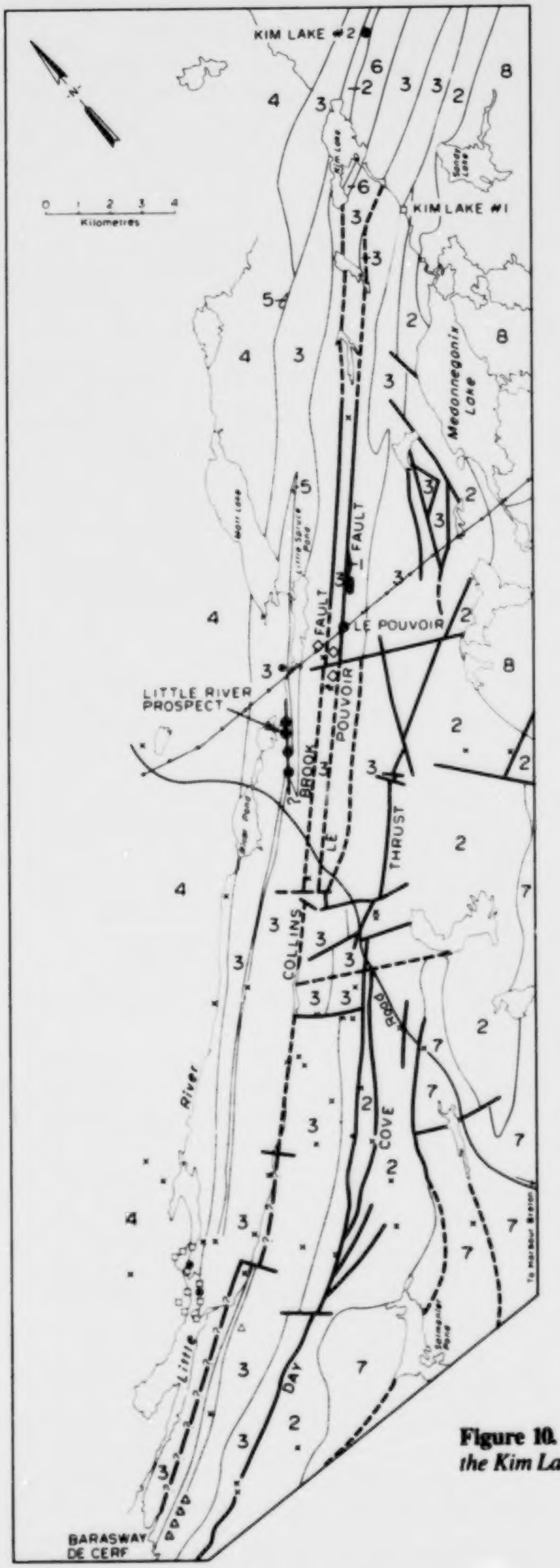
Hope Brook–Cinq Cerf

In southwest Newfoundland, the Hope Brook deposit (Figures 11 and 12) is a 400 by 60 m lens of fine grained silicified rock within the 5-km-long Chetwynd zone of pyrophyllite-sericite-silica alteration (McKenzie, 1986). Fine grained gold occurs with pyrite and minor chalcopyrite (generally less than 5 percent) disseminated throughout the deposit; elevated Sb and Ag values are present and minor tellurides, bismuthinite, cassiterite, native silver and tin have been noted. A pyrite-rich zone occurs immediately west of the ore deposit (Figure 12), and pyrophyllite–silica alteration occurs on the east. Significant gold intersections have also been obtained at the Chetwynd and Chetwynd South deposits within the Chetwynd alteration zone.

The host rocks and protolith to the altered zone are a sequence of felsic tuffs, volcaniclastic sediments and granitic intrusions of the La Poile Group (Chorlton, 1978, 1980; O'Brien, 1986). Post-alteration swarms of mafic dykes occur in the altered zone and in the host rocks to the east. The age of the rocks has not been determined, and could range from Early Cambrian to Silurian (B. O'Brien, 1987). The altered zone is intruded by the Devonian Chetwynd Granite at Hope Brook and may correlate with alteration at Peter Snout (Figure 6) northeast of the granite.

The alteration zone and the Hope Brook deposit have been deformed within the Cinq Cerf shear zone (Figure 11). Highly strained conglomerates and tuff are well exposed in Cinq Cerf Brook immediately west of the altered zone. Intrusion of the Chetwynd Granite postdated significant deformation on the Cinq Cerf shear zone.

The metallic mineral assemblages, and the spatial distribution of the alteration assemblages led McKenzie (1986)


KIM LAKE #2
KIM LAKE #1
0 1 2 3 4
Kilometres
Kim Lake
Sandy Lake
Medonnegonix Lake
Wolf Lake
Little Spruce Pond
LE POUVOIR
LE POUVOIR FAULT
FAULT
LITTLE RIVER PROSPECT
COLLINS BROOK
THRUST
ROGD
COVE
DAY
Little River
To Harbour Breton
Salmonier Pond
BARASWAY DE CERF
1
2
3
4
5
6
7
8

LEGEND

DEVONIAN

8 *Porphyritic biotite granite (massive)*

SILURIAN

7 *Granite, granodiorite, gabbro (foliated)*

ORDOVICIAN?

6 *Kaegudeck diabase*

5 *Granodiorite (sheared)*

MIDDLE ORDOVICIAN

4 Riches Island Formation: *greywacke*

3 Isle Galet Formation: *felsic and mafic volcanic rocks*

2 Little Passage Gneiss *(psammite)*

ORDOVICIAN OR OLDER

1 *Carbonatized ultramafics*

● *Au prospects and occurrences (+ Py, Po, Asp, Sb)*

▵ *Volcanogenic massive sulphides (Pb–Zn)*

◇ *Sb veins*

□ *Py-Po ± Sb veins*

× *Minor pyrite occurrence*

——— - - - *Faults (defined, inferred)*

Figure 10. *Simplified geology and mineral occurrences in the Kim Lake–Little River area; after Dickson* (this volume).

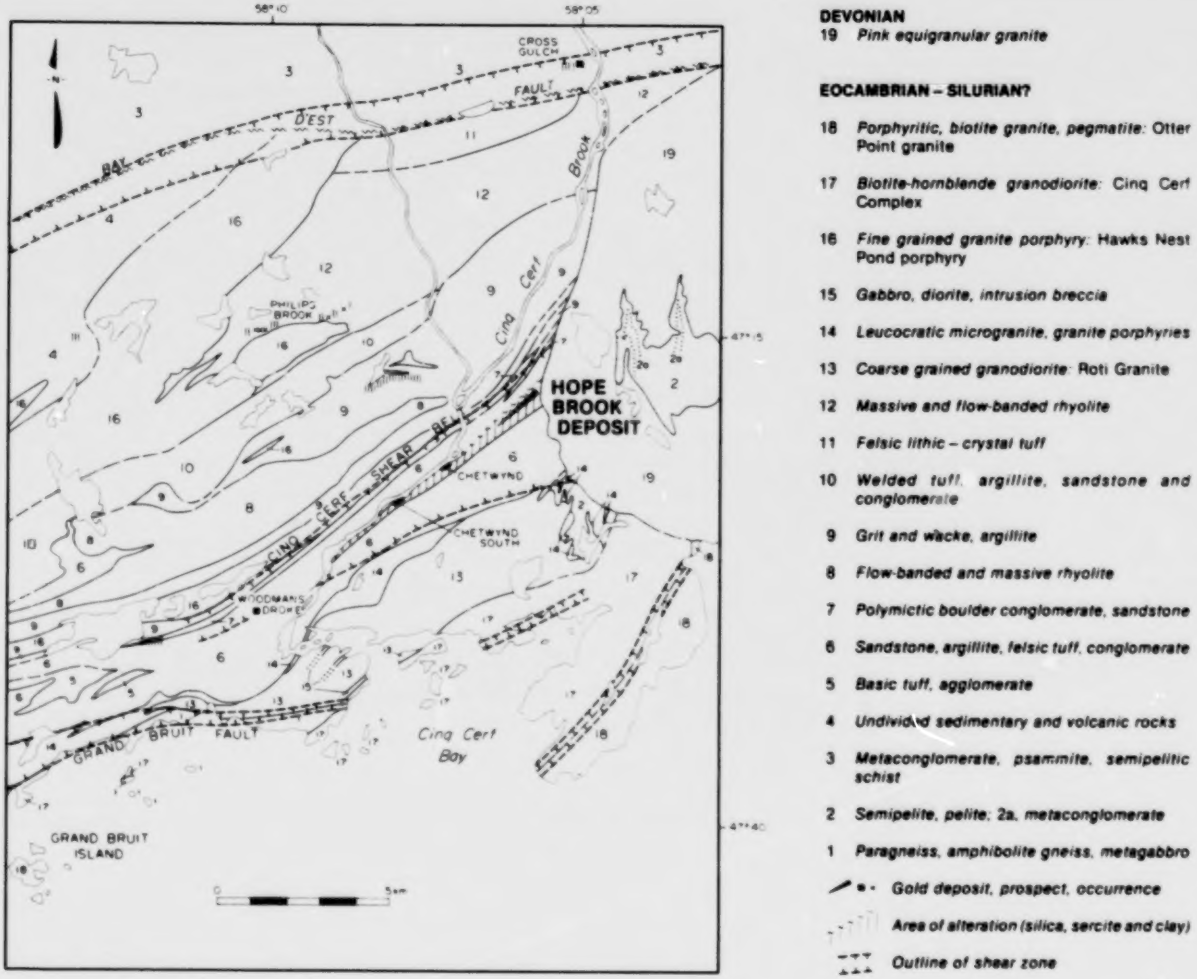

58°10'
58°05'
47°45'
47°40'
N
CROSS GULCH
BAY D'EST FAULT
Brook
Cinq Cerf
PHILIPS BROOK
HOPE BROOK DEPOSIT
CINQ CERF SHEAR BELT
CHETWYND
CHETWYND SOUTH
WOODMANS DROKE
GRAND BRUIT FAULT
Cinq Cerf Bay
GRAND BRUIT ISLAND
0
5km
DEVONIAN
19 Pink equigranular granite
EOCAMBRIAN – SILURIAN?
18 Porphyritic, biotite granite, pegmatite: Otter Point granite
17 Biotite-hornblende granodiorite: Cinq Cerf Complex
16 Fine grained granite porphyry: Hawks Nest Pond porphyry
15 Gabbro, diorite, intrusion breccia
14 Leucocratic microgranite, granite porphyries
13 Coarse grained granodiorite: Roti Granite
12 Massive and flow-banded rhyolite
11 Felsic lithic – crystal tuff
10 Welded tuff, argillite, sandstone and conglomerate
9 Grit and wacke, argillite
8 Flow-banded and massive rhyolite
7 Polymictic boulder conglomerate, sandstone
6 Sandstone, argillite, felsic tuff, conglomerate
5 Basic tuff, agglomerate
4 Undivided sedimentary and volcanic rocks
3 Metaconglomerate, psammite, semipelitic schist
2 Semipelite, pelite; 2a, metaconglomerate
1 Paragneiss, amphibolite gneiss, metagabbro
Gold deposit, prospect, occurrence
Area of alteration (silica, sercite and clay)
Outline of shear zone

Figure 11. *Generalized geology in the Cinq Cerf area showing the location of the Hope Brook Mine and other gold occurrences, major structures, and areas of pervasive hydrothermal alteration; after Chorlton (1978, 1980), McKenzie (1986), and O'Brien (1987).*

to propose an epithermal origin for the deposit (also see Swinden, 1984). However, this interpretation is complicated by tectonic overprinting, indicated by flattening textures in the ore zone. A contact metamorphic halo and the presence of fluorite suggests the possibility of hydrothermal fluids emanating from the Chetwynd Granite. Other models, such as localization of the deposit in a shear zone with fluid and gold derived from metamorphic devolatilization are also possible (cf. Colvine *et al.*, 1984).

Several other prospects are reported from the Cinq Cerf area (Tuach, 1987a), however, information is limited. The Bay D'Est Fault is a brittle fault within a zone of ductile deformation (Figure 11) that locally contains large areas of sericitized and pyritized rock. The Cross Gulch Gold Prospect is a silicified zone in one such area of sericite alteration hosted by the Bay Du Nord Group (D. MacInnis, personal communication, 1986). Post-tectonic, undeformed, hydrothermally brecciated quartz veins occur in some alteration zones (B. O'Brien, personal communication, 1986). Anomalous gold is also reported in quartz veins hosted by relatively undeformed rocks at the Woodmans Droke Prospect, and in relatively undeformed hydrothermal alteration zones at the Philips Brook occurrence (Tuach, 1987a).

Cape Ray

The Main Zone and the Windowglass Hill deposits occur within a belt of mylonitized rocks that define the Cape Ray Fault Zone (Wilton, 1984; Wilton and Strong, 1986; Figure 13). The Main Zone consists of three separate lenses of mineralized quartz veins (Figure 13) that are hosted by deformed, bedded and laminated, graphitic and chloritic sediments. The graphitic sediments occur within a

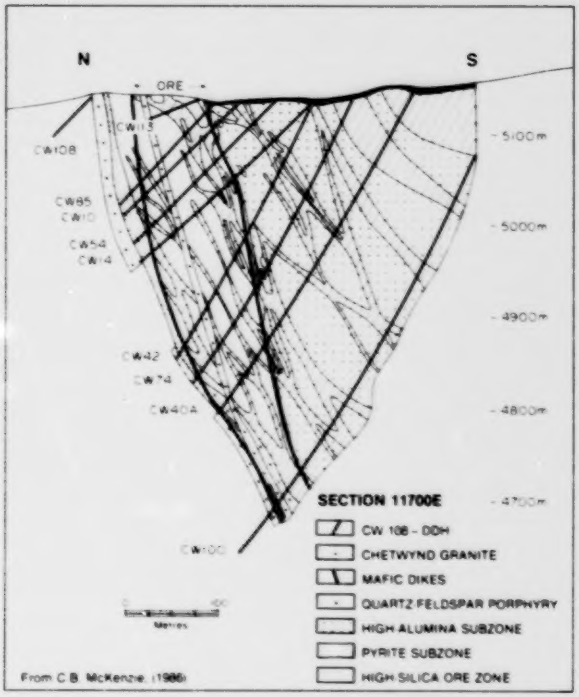

N
S
ORE
CW113
CW108
CW85
CW10
CW54
CW14
CW42
CW74
CW40A
CW100
5100m
5000m
4900m
4800m
4700m
SECTION 11700E
CW 108 - DDH
CHETWYND GRANITE
MAFIC DIKES
QUARTZ FELDSPAR PORPHYRY
HIGH ALUMINA SUBZONE
PYRITE SUBZONE
HIGH SILICA ORE ZONE
0
100
Metres
From C.B. McKenzie, (1986)

Figure 12. *Geological section across the Hope Brook deposit; from McKenzie (1986).*

penetratively deformed sequence of bedded to laminated mafic tuff and silicic pyroclastic rocks (Tuach, 1986). The Windowglass Hill deposit consists of sheeted quartz veins and stockwork quartz veins and veinlets hosted by albitized graphic granite. Hydrothermal breccia textures are locally well devleoped. In both deposits, gold occurs with silver as electrum and is associated with galena, sphalerite, chalcopyrite and pyrite in the quartz veins (Wilton and Strong, 1986).

The Main Zone veins are boudinaged and locally brecciated. Wilton (1984) interpreted the veins as occurring in chloritic and sericitic schist in a pre- to syntectonic 'Main Shear' separating the Devonian Windsor Point Group from the Ordovician or older Port Aux Basques Gneiss Complex. However, Tuach (1986) suggested that the mineralized lodes occur in a late brittle splay from the Cape Ray Fault in an undated sequence of volcanic and volcaniclastic rocks, and that brecciation and additional deformation occurred during late movement on the fault. Contrary to the description of Wilton and Strong (1986, page 292), the Windowglass Hill deposit has not been subject to intense deformation; intrusion and accompanying mineralization postdated the main movements on the fault zone. Therefore, it is likely that both deposits, with a comparable mineral and isotopic signature (Wilton and Strong, 1986), postdate the main deformation. The H and I Brook prospects adjacent to the Cape Ray mylonite are brecciated, probably by late movements.

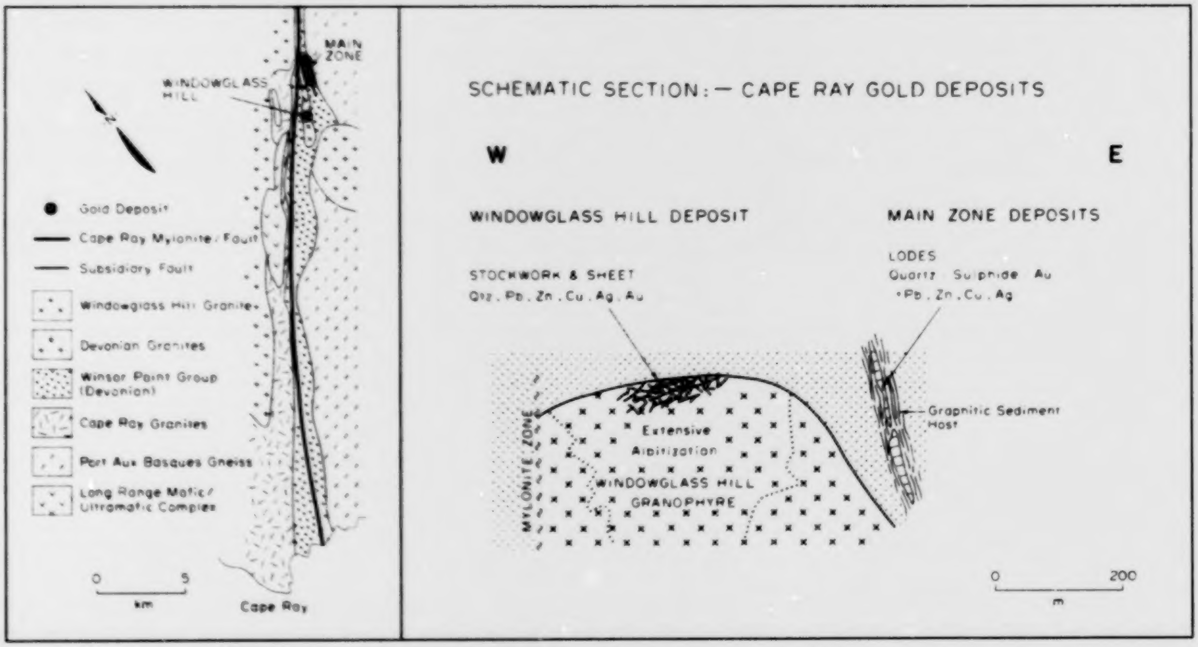
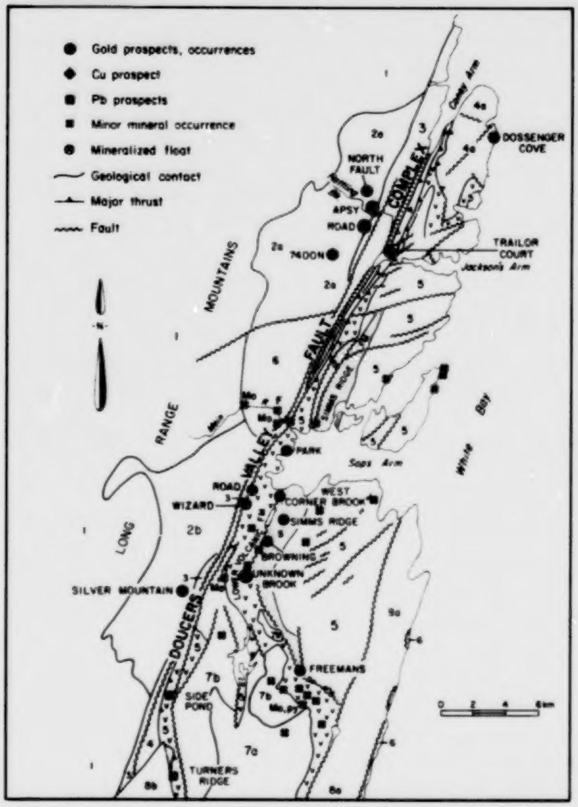

MAIN ZONE
WINDOWGLASS HILL
N
Gold Deposit
Cape Ray Mylonite / Fault
Subsidiary Fault
Windowglass Hill Granite
Devonian Granites
Winsor Point Group (Devonian)
Cape Ray Granites
Port Aux Basques Gneiss
Long Range Mafic / Ultramafic Complex
0
5
km
Cape Ray
SCHEMATIC SECTION:— CAPE RAY GOLD DEPOSITS
W
E
WINDOWGLASS HILL DEPOSIT
MAIN ZONE DEPOSITS
STOCKWORK & SHEET
Qtz, Pb, Zn, Cu, Ag, Au
LODES
Quartz Sulphide Au
+Pb, Zn, Cu, Ag
Graphitic Sediment Host
Extensive Albitization
WINDOWGLASS HILL GRANOPHYRE
MYLONITE ZONE
0
200
m

Figure 13. *(A) Generalized geology of the Cape Ray Fault Zone showing location of gold deposits and occurrences; (B) schematic section showing settings of mineralization; after Wilton (1984) and Tuach (1986).*


Gold prospects, occurrences
Cu prospect
Pb prospects
Minor mineral occurrence
Mineralized float
Geological contact
Major thrust
Fault
-N-
0 2 4 6km
MOUNTAINS
RANGE
LONG
DOUCERS
VALLEY
FAULT
COMPLEX
Coney Arm
DOSSENGER COVE
NORTH FAULT
APSY
ROAD
74DON
TRAILOR COURT
Jackson's Arm
Simms Ridge
PARK
Sops Arm
White Bay
ROAD
WIZARD
WEST CORNER BROOK
SIMMS RIDGE
BROWNING
UNKNOWN BROOK
Lower Volcanic Fm
SILVER MOUNTAIN
FREEMANS
SIDE POND
TURNERS RIDGE
Mo
Mo, py
F
1
2a
2b
3
4
4a
5
6
7a
7b
8a
8b

UPPER PALEOZOIC (Basin-fill sequences and intrusions)

CARBONIFEROUS

8 8a, Anguille Group (Tournaisian): *greywacke, shale, minor sandstone and conglomerate;* 8b, Deer Lake Group (Visean): *conglomerate, sandstone, siltstone:*

DEVONIAN (approximately 398 Ma)

7 Gull Lake intrusive suite: 7a, *granites;* 7b, *intermediate and mafic intrusive rocks*

6 Devils Room granite

SILURIAN

5 Sops Arm Group

LOWER PALEOZOIC ALLOCHTHON

CAMBRIAN–MIDDLE ORDOVICIAN

4 Southern White Bay Allochthon: *partially ophiolitic (mélange containing ultramafic blocks is cross-hatched)* 4a, Coney Head Complex

LOWER PALEOZOIC AUTOCHTHON (Platform)

3 Coney Arm Group: *carbonate, shale, quartzite*

PRECAMBRIAN (Grenvillian basement)

MIDDLE PROTEROZOIC AND EARLIER

2 *Massive to foliated, feldspar-megacrystic, granitoid plutons; 2a, Aspy pluton; 2b, Main River granite*

1 *Leucocratic gneiss, amphibolite, and gabbro*

Figure 14. *Simplified geology and mineral occurrences in Western White Bay from Tuach (1987b). The Lower Volcanic formation and the Simms Ridge Formation of the Sops Arm Group are patterned.*

Wilton (1984) and Wilton and Strong (1986) reported results of geochemical, isotopic and phase equilibra studies, and concluded that the gold deposits and prospects in the Cape Ray area were formed from magmatic-hydrothermal fluids exsolved as a vapour phase from the Windowglass Hill Granite. Temperatures of ore formation were estimated at 300°C. A schematic representation of the mineralization is presented in Figure 13.

Western White Bay

Gold mineralization of potential economic significance has been identified in western White Bay near Jackson's Arm and to the south of Sops Arm at Unknown Brook (Figure 14). Numerous other mineral occurrences are present, and a spatial relationship between mineralization and the Doucers Valley fault complex is evident (Tuach, 1987b).

The Jackson's Arm alteration system and associated gold mineralization overprint foliated, megacrystic granodiorite of Late Grenvillian age (Bruneau, 1984; Tuach and French, 1986; Saunders and Tuach, *this volume).* Mineralization and alteration has been recently reported in Eocambrian to Cambrian sedimentary rocks that unconformably overlie the Grenvillian granitoid rocks (McKenzie, 1987). In the granitoid rocks, K-feldspathization of original plagioclase occurred over large areas (up to 2 km) and is pervasively developed in the core of the alteration system. K-feldspar is also developed marginal to veins in the periphery of the alteration system. In the pervasively altered rocks, fracture stockworks and areas of hydrothermal breccia contain fine grained albite, Fe-carbonate, minor quartz, pyrite and arsenopyrite and locally contain gold associated with the sulphides. Shear zones and veins containing albite and sulphides are exposed in the periphery of the system.

Gold and base-metal-bearing quartz veins occur at a number of localities in Silurian silicic volcaniclastic and sedimentary rocks to the south of Sops Arm (Figure 14). West-directed thrust and folds occurred during the Late Silurian prior to intrusion of the Gull Lake intrusive suite.

The most significant deposit outlined to date is at Unknown Brook where quartz–carbonate–alkali feldspar–pyrite veins occur in a conglomerate bed above and parallel to a thrust plane. The thrust plane is defined by rodded quartz nodules in a sericite alteration zone (Figure 15). The Browning Mine overlies a thrust plane defined by a chlorite schist horizon; anomalous gold is present in both boudinaged and broken veins oriented parallel to foliation, and in crosscutting veins. Several showings occur as gash-veins in massive felsic tuffs (Park and West Corner Brook), and others

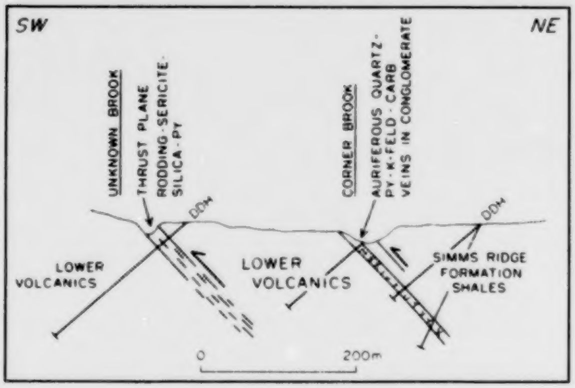

SW
NE
UNKNOWN BROOK
THRUST PLANE
RODDING-SERICITE-SILICA-PY
DDH
CORNER BROOK
AURIFEROUS QUARTZ-PY-K-FELD-CARB VEINS IN CONGLOMERATE
DDH
LOWER VOLCANICS
LOWER VOLCANICS
SIMMS RIDGE FORMATION SHALES
0
200m

Figure 15. *Schematic section of the geology in the vicinity of the Unknown Brook deposit, Sops Arm area (Brad Mercer, personal communication, 1987). The altered zone in Unknown Brook is interpreted to represent a thrust plane. The mineralized zone represents tensional fractures in a more competent horizon.*

are located within the Doucers Valley fault complex as deformed and boudinaged veins (Wizard, Road) in areas of Carboniferous brittle movement. Siderite cubes are characteristic of the Simms Ridge Formation and increase in abundance toward the known mineralization at the Browning Mine and at Simms Ridge. These siderite cubes probably represent an outer (propylitic) alteration facies related to the hydrothermal systems. Therefore, the Simms Ridge Formation outlines the areal extent of the hydrothermal systems in the Silurian of White Bay.

The environment and age of gold deposition in western White Bay is equivocal. Tuach (1986) suggested that the Silurian alteration and associated mineral deposits were dominantly epithermal. However, the presence of ductile thrust zones in less competent rocks, and tensional mineralized veins in the more competent rocks, suggests a depth of vein formation in excess of 3 km and the possibility that detachment thrust models are applicable. The discovery of gold mineralization in Paleozoic rocks at Jackson's Arm negates the suggestion that the mineralizing system was Eocambrian (Tuach and French, 1986).

Baie Verte Peninsula

Vein-type mineralization in the Baie Verte Peninsula (Figure 16) is predominantly associated with Ordovician, ophiolitic, ultramafic and mafic rocks that occur as slivers within fault and thrust zones. The most prominent fault zones are in the Baie Verte Lineament and in the Tilt Cove–Betts Cove ophiolite belt (Hibbard, 1984). Minor gold-mineralized quartz veins have also been reported in the Rambler area in the vicinity of massive sulphide deposits (cf. Hibbard, 1984).

The recently discovered Deer Cove Prospect near Mings Bight is the best defined lode-gold prospect (Gower *et al.*, *in press*). It is a quartz and quartz-breccia vein in relatively unstrained pillow lavas and breccias overlying a moderately north-dipping thrust zone (the Deer Cove Thrust) that developed in sheared talc-carbonate rocks (Figure 17). The main zone has a northerly trend and has been traced for a distance of 500 m. It varies from 1 to 3 m wide and dips at aproximately 45 degrees to the west. Numerous other auriferous quartz veins are developed within mafic lavas, diabase, and gabbros throughout this area.

The Goldenville Mine produced approximately 4.6 kg Au in 1906; the surrounding area has been intermittently explored for gold since that time. The gold is located in quartz–pyrite veins and veinlets adjacent to and within a ferruginous iron formation that has been traced over a distance of 4 km. The Goldenville Mine appears to occur at the intersection of a north-trending structure and the iron formation.

Minor gold occurrences in quartz veins and shear zones have been reported throughout the ophiolitic Betts Cove Complex (Figure 16). The showings occur in talc-carbonate, gabbro, diabase, mafic pillow volcanics, mafic sediments and ferriginous chert horizons.

Several new prospects have recently been reported from the Baie Verte Lineament in the vicinity of Baie Verte (International Wildcat, 1987, International Impala, 1987). They occur as quartz veins and shear zones in a variety of deformed ophiolitic rocks. A showing at Marble Cove is hosted by clastic metasediments of the Fleur de Lys Supergroup (Unit 2 on Figure 16).

The spatial relationship of gold mineralization to fault zones with carbonatized ophiolitic ultramafic rocks suggests a direct comparison with the Mother Lode Belt in California (Landefeld and Silberman, 1987; Weir and Kerrick, 1987) and with similar deposits in British Columbia (Nesbitt *et al.*, 1986). Talc–carbonate–chrome-mica alteration of serpentinized ultramafic rocks is common, resulting in a bright green rock locally known as virginite (mariposite in California). The listwaenite alteration model (Buisson and LeBlanc, 1986; Figure 18) that invokes carbonitization of serpentinized ultramafic rocks and development of gold veins in and above thrusts and reverse and normal faults, has been a useful guide to exploration in the Baie Verte Peninsula (D. MacInnis, personal communication, 1987). Locally, the thrust zones associated with the ophiolites are defined by mélange.

Central Newfoundland–Victoria Lake

Most of the known prospects are hosted by rocks of the Tulks Hill volcanics of the Ordovician Victoria Lake Group (Figure 19; Kean and Jayasinghe, 1981). Epigenetic mineralization is associated with faults or shear zones, however, alteration assemblages characteristic of epithermal environments are locally well developed (Evans and Kean, 1987).

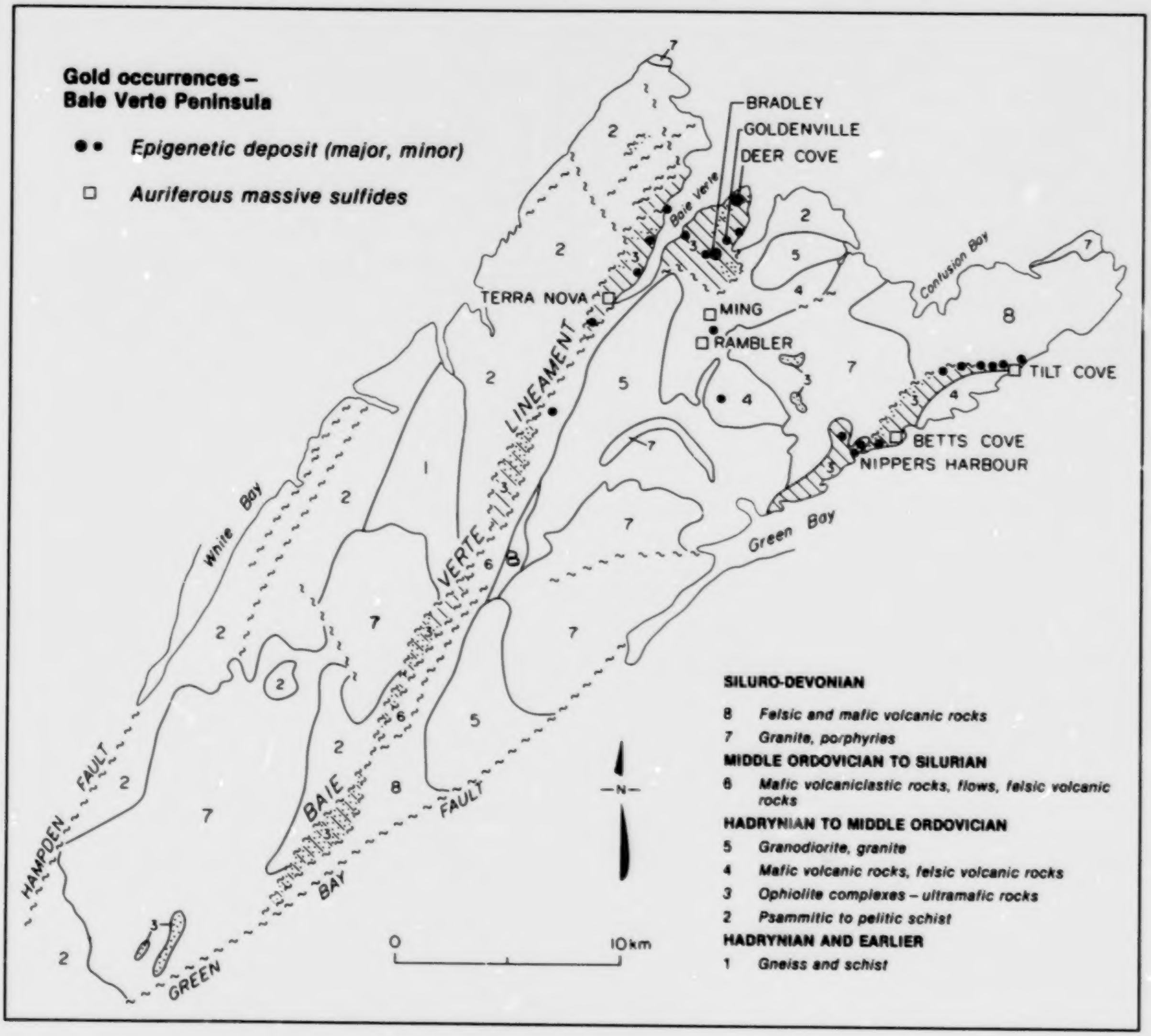

Gold occurrences –
Baie Verte Peninsula
●• Epigenetic deposit (major, minor)
□ Auriferous massive sulfides
BRADLEY
GOLDENVILLE
DEER COVE
Baie Verte
Confusion Bay
TERRA NOVA
MING
RAMBLER
TILT COVE
BETTS COVE
NIPPERS HARBOUR
Green Bay
White Bay
BAIE VERTE LINEAMENT
HAMPDEN FAULT
BAIE FAULT
GREEN BAY
N
0
10km
SILURO-DEVONIAN
8 Felsic and mafic volcanic rocks
7 Granite, porphyries
MIDDLE ORDOVICIAN TO SILURIAN
6 Mafic volcaniclastic rocks, flows, felsic volcanic rocks
HADRYNIAN TO MIDDLE ORDOVICIAN
5 Granodiorite, granite
4 Mafic volcanic rocks, felsic volcanic rocks
3 Ophiolite complexes – ultramafic rocks
2 Psammitic to pelitic schist
HADRYNIAN AND EARLIER
1 Gneiss and schist

Figure 16. *Geology and location of gold occurrences on the Baie Verte Peninsula; after Hibbard (1984), Tuach (1987a), International Impala (1987), International Wildcat (1987). Ophiolitic rocks are lined, ultramafic rocks are lined and stippled. Unit 2 is the Fleur de Lys Supergroup, Unit 4 is the Pacquet Harbour Group.*

The Midas Pond Prospect (Figure 20) occurs to the east of the Tulks Valley Fault in sheared felsic and intermediate pyroclastic rocks of the Tulks Hill volcanics (Evans and Kean, 1987). It consists of a subvertical zone (maximum width of 12 m) of crosscutting quartz–carbonate–tourmaline–pyrite veins. Veins vary from foliation-parallel to crosscutting, with anomalous gold content present in both varieties. A 70 by 800 m area of pyrophyllite–kaolinite–sericite–silica alteration is present in the structural hanging wall of the mineralized zone. Banded, carbonate-rich mafic rocks with up to 5 percent pyrite occur in the vein zone and in the structural footwall; significant gold values occur in these pyrite-rich mafic rocks. The mineralization and alteration have been variably deformed in a 300 m wide shear zone (Figure 20).

Banded, massive, silicified, felsic volcanic rocks at Bobbys Pond contain an alteration assemblage of pyrophyllite, sericite, native sulphur and orpiment (Kean and Evans, *this volume).* Semimassive pyrite with pyrophyllite–sericite–silica alteration is developed in similar rocks at North Pond, 2.5 km to the northeast. The silicified zones appear to form boudins in less competent sericitized rocks in a shear zone. Minor anomalous gold is locally present within the enclosing sericite schist.

Evans and Kean (1987) noted the similarity in the alteration at Midas Pond to that of epithermal gold systems, but were uncertain as to the age and genetic significance of the enclosing shear zone, i.e., did the alteration provide a

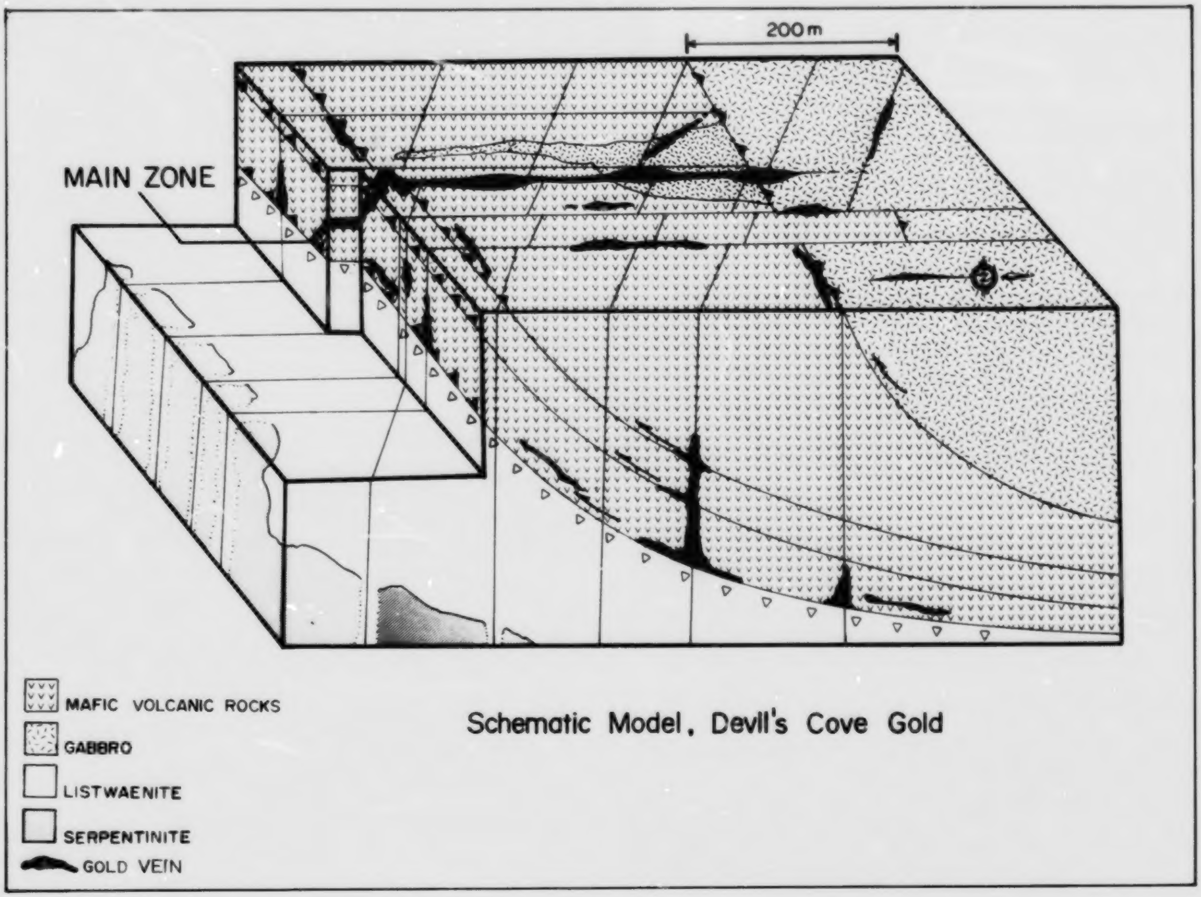


Figure 17. *Schematic section of the geology at the Deer Cove prospect; from Gower* et al. (in press).

favorable site for shearing or did the shear zone provide a conduit for epithermal fluids. Similar alteration and genetic ambiguities occur at Bobbys Pond.

An extensive zone of silicified, banded, and possibly mylonitized, chert or volcanic rocks occurs at West Tulks to the west of the Tulks Valley Fault (Figure 19). Gold occurs both in chert-like siliceous rocks and in galena–chalcopyrite-bearing quartz veins. Similar rocks occur along strike at Stag Pond. The Road or Camp Showing, located in the southern end of Tulks Valley, consists of narrow auriferous galena–sphalerite–pyrite-bearing quartz veins in sheared, sericitized and carbonatized felsic volcanic rocks. Both of these showings may have formed in shear zones related to the Tulks Valley lineament.

Visible gold, galena, sphalerite and specular hematite occur in 1 to 2 cm wide quartz–carbonate veins at the Second Exploits showing (Kean, 1984). The veins cut Ordovician (?) granite of the Lloyds River intrusive suite and are situated in a splay of the Cape Ray Fault (Kean, 1984). Devonian sedimentary rocks nonconformably overlie the granites.

At Valentine Lake (Figure 19), sheeted and stockwork quartz–tourmaline veins occur over an area of 20 km^2 in the Valentine Lake quartz monzonite. Numerous occurrences of free gold associated with minor pyrite and andradite are reported in the veins (Kean and Evans, *this volume).* The mineralization is adjacent to the Silurian(?) Rogerson Lake Conglomerate that contains boulders of the quartz monzonite. The outcrop pattern of the conglomerate is linear and probably defines a major fault in central Newfoundland (Kean, 1984). Veining is also reported in the conglomerate overlying the quartz monzonite, which suggests that the granite merely acted as a brittle host to later genetically unrelated mineralizing fluids.

On an island in Long Lake, auriferous, pyritic quartz veins occur in granite and aplite, which intruded into a narrow (3 m) shear zone in relatively undeformed pillow lavas. Tight, isoclinally folded and boudinaged quartz veins occur in the shear zone, although the aplite and granite are not penetratively deformed. The gold mineralization at this showing may be related to intrusion of the granitic host.

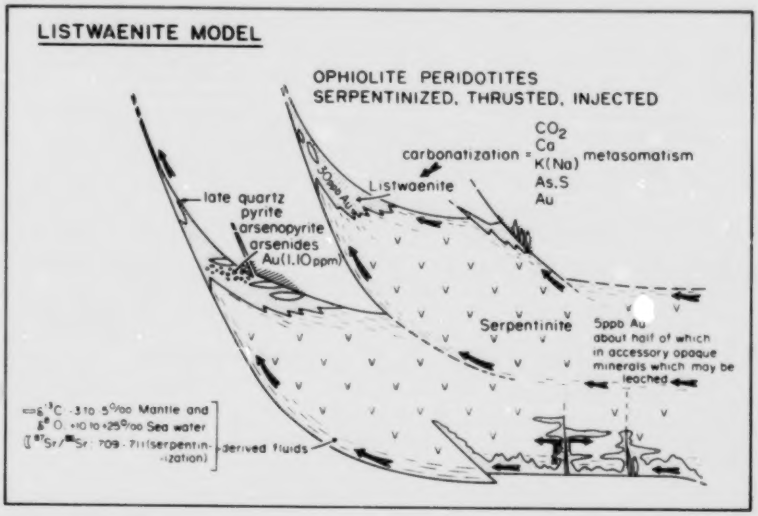


Figure 18. *The listwaenite model of gold mineralization, from Buisson and Leblanc (1986).*

In summary, many of the prospects and occurrences are adjacent to major faults or in shear zones. The structural controls of mineralization are further emphasized by the coincidence of mineralization with linears defined by regional analyses of topographic structures and magnetic gradiometer anomalies (Kean and Evans, *this volume)*. In particular, mineralization with associated epithermal-style alteration in the Tulks Hill volcanics may occur in northeast-trending linears; these linears may have developed over earlier synvolcanic structures. However, considerable remobilization of gold probably occurred during progressive deformation. Alternatively, epithermal systems may have developed in the late Paleozoic at high crustal levels and were deformed in later shearing.

Other occurrences and prospects in diverse lithologies are associated with structures of various orientations. Formation of these deposits (cf. West Tulks, Valentine Lake) may be related to the development of shear zones at greater depths. The Long Lake Prospect suggests that plutonism may have been an important local control.

Other Areas

Several important showings and occurrences have not been described above. The Moretons Harbour prospects (Figure 6) consist of auriferous quartz veins with Sb, As and minor base metals hosted by Ordovician volcanics with local sericite alteration. The veins are considered as stratabound (Strong and Payne, 1973). Fluid inclusion studies (Kay and Strong, 1983) and lead isotope analyses (Swinden, unpublished data) indicate that the veins formed during growth of the volcanic pile, and may form part of a volcanogenic stockwork system. Similar environments may be present throughout central Newfoundland, particularly in the deeper levels of massive sulphide systems.

At the Handcamp Prospect (Figure 6), gold mineralization was discovered in 1928 in association with pyrite, chalcopyrite, sphalerite, and minor galena. It is hosted by altered mafic and felsic volcanics and volcaniclastic rocks and minor ferruginous chert beds of the Roberts Arm Group (Swinden and Sacks, 1986). Erratic high-grade gold values have been reported but a significant tonnage of ore has not been defined by drilling. Mineralization has been correlated with volcanogenic sulphide deposits at Gullbridge, Pilleys Island and Buchans (Figure 2). However, alternative genetic models involving later epigenetic fluids are possible.

Many occurrences throughout Newfoundland are associated with ophiolitic rocks and associated deformation zones (Figure 6). In the GRUB line (Figure 6), the Jonathon's Pond and Weir's Pond prospects north of Gander (O'Neill, 1987), and the recently discovered prospects at Great Bend (Figure 6), contain arsenopyrite as the dominant gangue sulphide. Numerous occurrences are reported from the ophiolite klippe in western Newfoundland (Figure 6). Carbonate alteration is widespread in ultramafic rocks to the east of Deer Lake and on Glover Island, and showings are reported on Glover Island. Further work is required to categorize these environments.

In addition to mineralization described above, gold has been discovered in numerous other geological environments. For example, auriferous quartz veins are reported at Wing Pond in the Gander Group (O'Neill, *this volume)*, in quartz veins in the Ordovician Davidsville Group (D. MacInnis, personal communication) in the Silurian Indian Islands Group (McGillivray, 1985), and in carbonatized mafic dykes at Canada Bay (Knight (1987),

EPIGENETIC DEPOSITS AND MAJOR STRUCTURES

Most of the epigenetic deposits and occurrences described above are localized in secondary structural environments that are spatially (Figure 6) related to major north-northeast and northeast faults and lineaments of the Appalachian Orogen. These lineaments are defined by some combination of major shear zones and fault complexes separating areas of contrasting geology, carbonatized and serpentinized remnants of ophiolitic ultramafic rocks, unconformities and associated linear conglomerate sequences, geophysical contrasts, and/or topographic depressions.

Some of the lineaments may have originated as block faults during the Eocambrian rifting that formed the Iapetus Ocean followed by multiple reactivation of these lineaments

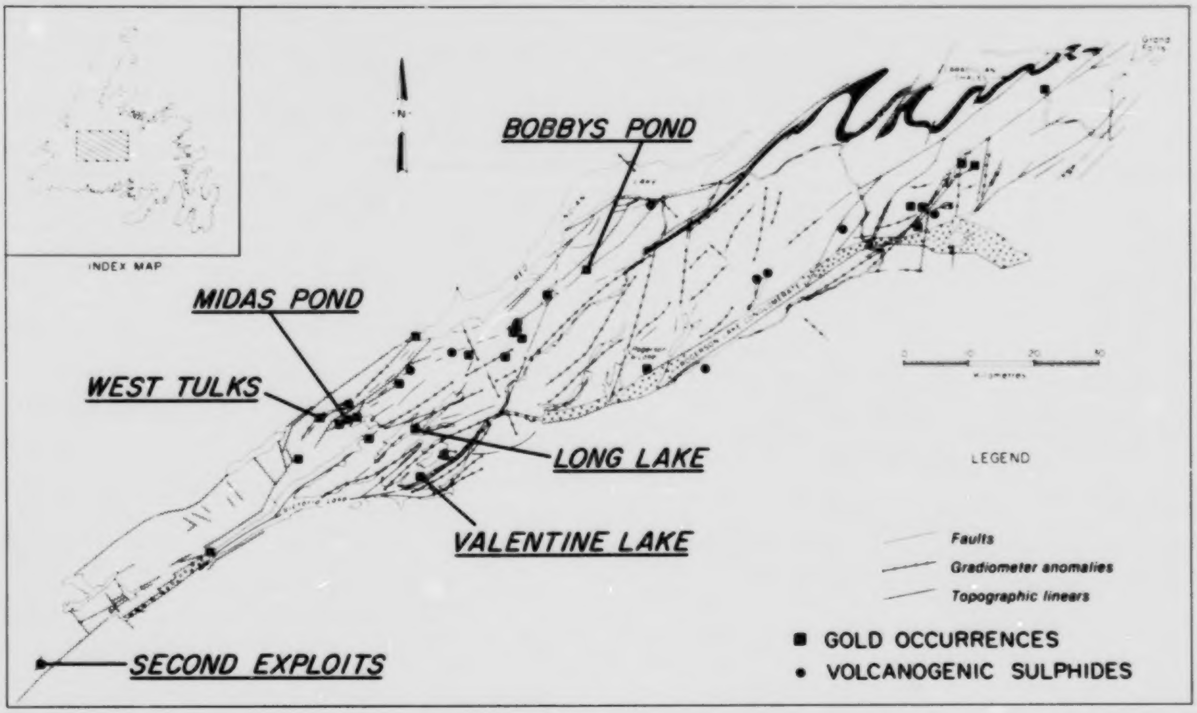


Figure 19. *Simplified geology, structure and location of epigenetic gold occurrences in the Buchans–Victoria Lake area, central Newfoundland; from Kean and Evans* (this volume).

and deformation (including thrusting and backthrusting) of overlying rocks during subsequent Paleozoic orogenic events (i.e., Baie Verte Lineament, Doucers Valley Fault Complex; Tuach, 1987b); other lineaments have been interpreted as accretionary terrane boundaries (Hermitage Bay–Dover Fault; Williams and Hatcher, 1982); others record major Ordovician–Silurian thrust planes (Pipestone Pond Fault, GRUB line; Colman-Sadd and Swinden, 1982; Stockmal *et al.*, 1987) or Acadian and Carboniferous transcurrent movements (Cape Ray Fault, Cabot Fault; Hyde, 1979).

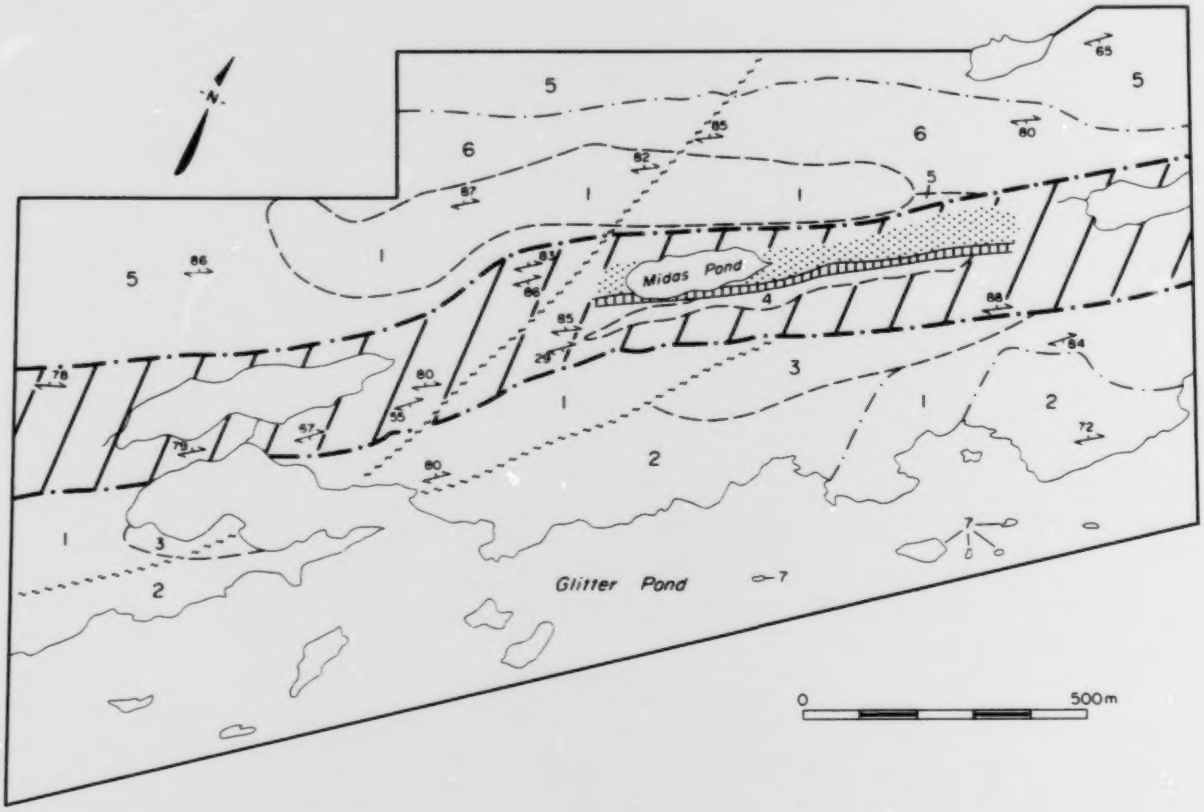
A genetic association between gold mineralization and major structures is implied. Movement on fault zones in the lineaments may have enhanced and focussed fluid systems and possibly magmatism, although a spatial and genetic association between plutonism and gold has not been generally well established. The genetic association between major faults and gold-bearing hydrothermal systems is emphasized by the presence of extensive lake sediment geochemical halos of a variety of gold-associated elements (As, Sb, W) around the major faults, i.e., Figure 21.

LATENT GOLD ENVIRONMENTS AND MODELS

Other geological environments with potential for gold mineralization are present in Newfoundland, although no gold has yet been reported.

Rocks of the Fleur de Lys Supergroup (Unit 2 on Figure 16) on the Baie Verte Peninsula have been correlated with the Dalradian of Ireland (Kennedy *et al.* 1972). These Dalradian rocks host the Gortin deposit in the Sperrin Mountains of Northern Ireland which contains 1.0 million tonnes grading 10.0 g/t Au. It occurs in quartz veins in a fault cutting polydeformed Dalradian metasediments (Clifford, 1986; Morris, 1987). Other important prospects are also located in crosscutting fault zones in Dalradian metasediments in Mayo and Donegal (Morris, 1987). Clearly, a similar potential exists in late faults throughout the Fleur de Lys Supergroup and in correlative rocks in Newfoundland.

Sulphide-bearing iron formations, termed Fox Neck (Nickeys Nose)-type deposits (Kean, 1983, 1984) are interbedded with argillite at the top of the ophiolitic pillow lava unit of the Lushs Bight Group (Figure 5). The rocks are also considered to form the stratigraphic base of the overlying island-arc sequences. The deposits are typically thin and discontinuous, but the stratigraphic units can be traced over a considerable distance. The iron formation is dominantly pyritic, but jasper and magnetite layers are common. A similar unit is present at the top of the pillow lavas in the Betts Cove ophiolite, and the Goldenville iron formation (Figure 16; Table 2) may be in a similar setting. Those iron formations described above from an ophiolite setting, and iron formations in the overlying island arc sequences, have potential for associated gold mineralization.



EARLY ORDOVICIAN

VICTORIA LAKE GROUP

7 *Gabbro*

6 *Silicified felsic tuff*

5 *Felsic crystal tuff, sericitic*

4 *Banded mafic rock, minor limonitic felsic bands*

3 *Felsic crystal tuff and minor breccia, sericitic, locally siliceous*

2 *Breccia; intermediate to mafic, minor tuff*

1 *Mafic, feldspar-crystal tuff and minor breccia*

∼∼∼∼∼∼ *Fault (assumed)*

— — —·— *Geological contact (approximate, gradational)*

↗ *Cleavage (inclined)*

·I·I *Anastomosing shear zone consisting of interbanded felsic crystal tuff, lapilli tuff and fine grained, mafic, crystal tuff variably pyrophyllitized and silicified*

░ *Extensively pyrophyllitized and locally silicified, felsic crystal tuff and lapilli tuff*

▥▥▥ *Mineralized zone consisting of pyritiferous quartz veins cutting silicified felsic rocks and in part the banded mafic rocks of Unit 4*

Figure 20. *Geology of the Midas Pond area; from Evans and Kean (1987).*

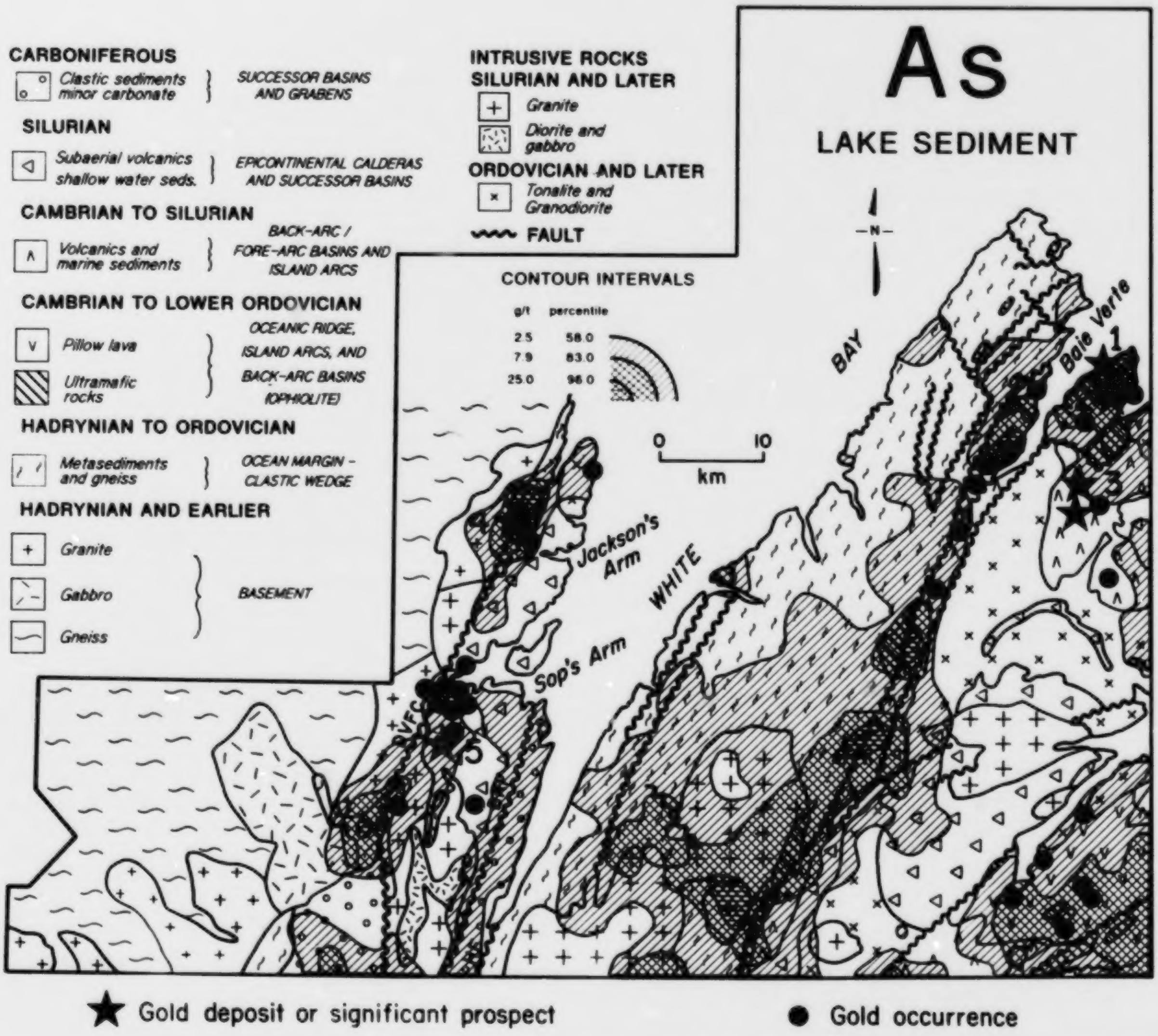

As
LAKE SEDIMENT
CARBONIFEROUS
Clastic sediments minor carbonate
SUCCESSOR BASINS AND GRABENS
SILURIAN
Subaerial volcanics shallow water seds.
EPICONTINENTAL CALDERAS AND SUCCESSOR BASINS
CAMBRIAN TO SILURIAN
Volcanics and marine sediments
BACK-ARC / FORE-ARC BASINS AND ISLAND ARCS
CAMBRIAN TO LOWER ORDOVICIAN
Pillow lava
Ultramafic rocks
OCEANIC RIDGE, ISLAND ARCS, AND BACK-ARC BASINS (OPHIOLITE)
HADRYNIAN TO ORDOVICIAN
Metasediments and gneiss
OCEAN MARGIN - CLASTIC WEDGE
HADRYNIAN AND EARLIER
Granite
Gabbro
Gneiss
BASEMENT
INTRUSIVE ROCKS
SILURIAN AND LATER
Granite
Diorite and gabbro
ORDOVICIAN AND LATER
Tonalite and Granodiorite
FAULT
CONTOUR INTERVALS
g/t percentile
2.5 58.0
7.9 83.0
25.0 96.0
0 10
km
N
BAY
WHITE
Baie Verte
Jackson's Arm
Sop's Arm
1
3
5
★ Gold deposit or significant prospect
● Gold occurrence

Figure 21. *Arsenic anomalies in lake sediments and major structures in the White Bay area; from Davenport and McConnell* (in press).

Thrusting and plutonism occur locally in the lower Paleozoic platformal clastic and carbonate sequences in the Western Platform and in the Avalon Zone. An analogy to the geological environment of the Carlin area in Nevada can be made.

Caldera environments are represented by Middle to Late Paleozoic volcanic and clastic sequences in central Newfoundland (Coyle and Strong, 1987), and may have associated epithermal deposits. The aluminous alteration and associated mineralization in the Avalon Zone may also be related to Late Hadrynian caldera development.

Lower to middle Paleozoic turbidite sequences in central Newfoundland may contain turbidite-hosted deposits and are similar in age and lithology to the Meguma Group of Nova Scotia. Therefore, the occurrences in the Davidsville Group may have a turbidite association.

DISCUSSION AND CONCLUSIONS

The continued importance and potential of gold-bearing massive sulphide deposits is emphasized by the recent discovery in the Duck Pond–Tally Pond area, and by the gold potential of the tailings pond at Rambler (Newfoundland

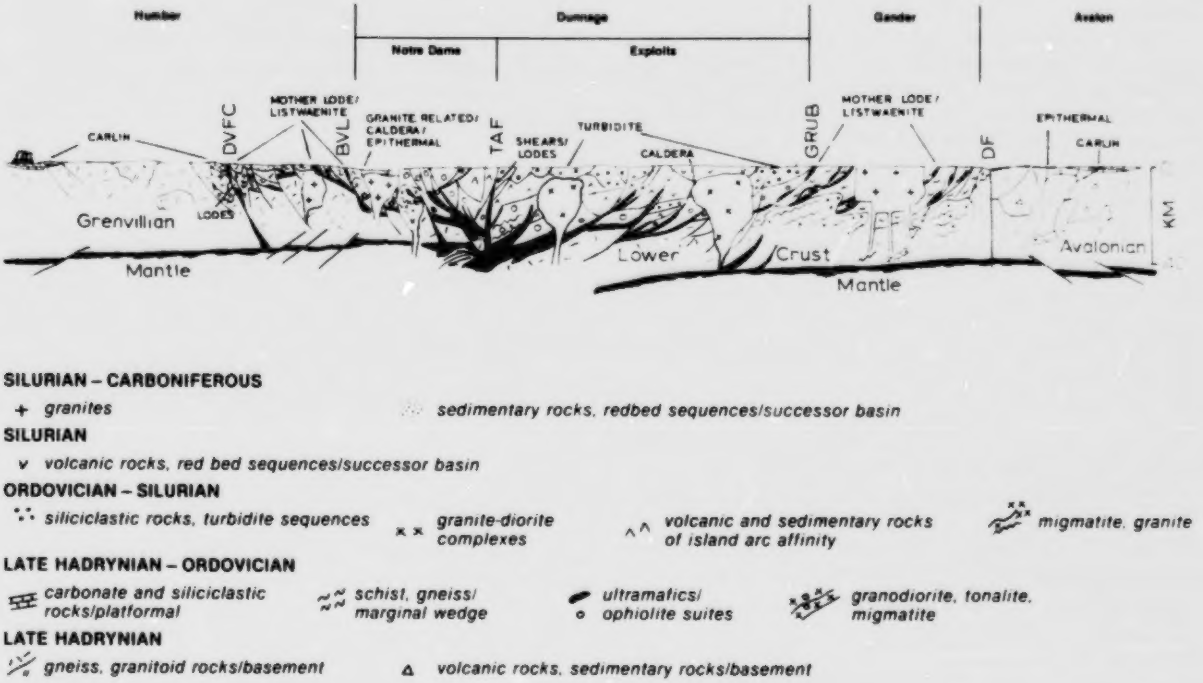

Humber
Dunnage
Notre Dame
Exploits
Gander
Avalon
CARLIN
DVFC
MOTHER LODE/
LISTWAENITE
BVL
GRANITE RELATED/
CALDERA/
EPITHERMAL
TAF
SHEARS/
LODES
TURBIDITE
CALDERA
GRUB
MOTHER LODE/
LISTWAENITE
DF
EPITHERMAL
CARLIN
KM
Grenvillian
LODES
Mantle
Lower
Crust
Mantle
Avalonian
SILURIAN – CARBONIFEROUS
granites
sedimentary rocks, redbed sequences/successor basin
SILURIAN
volcanic rocks, red bed sequences/successor basin
ORDOVICIAN – SILURIAN
siliciclastic rocks, turbidite sequences
granite-diorite complexes
volcanic and sedimentary rocks of island arc affinity
migmatite, granite
LATE HADRYNIAN – ORDOVICIAN
carbonate and siliciclastic rocks/platformal
schist, gneiss/ marginal wedge
ultramafics/ ophiolite suites
granodiorite, tonalite, migmatite
LATE HADRYNIAN
gneiss, granitoid rocks/basement
volcanic rocks, sedimentary rocks/basement

Figure 22. *Schematic geological section across Newfoundland showing environments of formation of epigenetic gold deposits. Approximate position shown on Figure 1. Section shows influence of basement faults and widespread low angle thrust zones. Note the extensive subsurface distribution of ultramafic rocks indicated by their presence along major thrust planes. Structural interpretations based on Keen* et al., *(1986), Stockmal* et al., *(1987) and S.P. Colman-Sadd (personal communication). DVFC, Doucers Valley Fault Complex; BVL, Baie Verte Line; TAF, Tommys Arm Fault; GRUB, Gander River Ultrabasic Belt; DF, Dover Fault.*

Department of Mines, 1987). Gold-bearing polymetallic deposits in mafic-felsic sequences and ophiolite-hosted massive sulphides provide an extremely attractive exploration target in Newfoundland. Variations in the relative metal contents of massive sulphide deposits mainly reflect the lithologies of the substrate from which the hydrothermal cells derived their metals.

Collectively, the new discoveries of epigentic gold mineralization in Newfoundland exhibit features common to gold deposits worldwide, and analogies to many of the major deposits can be made. The associations of gold, major faults and lineaments, sericite–carbonate–silica–clay-altered rocks, and carbonatized and serpentinized ultramafic rocks are proving to be effective exploration tools. However, the absence of one or all of these features does not preclude mineralization. Models involving epithermal alteration (Berger and Eimon, 1983) and listwaenite alteration (Buisson and LeBlanc, 1986) are locally applicable, and models involving metamorphic devolitatization (Colvine *et al.*, 1984) may also be relevant. Undoubtably other models will be developed and utilized as more information becomes available. A schematic section across Newfoundland that attempts to summarize the settings of known deposits and potential mineralized environments is presented in Figure 22.

The age of the gold systems has not been established in most cases. The epithermal systems in the Avalon Zone are probably Late Hadrynian. Systems that display deformed alteration assemblages characteristic of epithermal environments such as Hope Brook and Midas Pond may have developed during waning stages of volcanism (Cambrian to Silurian) prior to later deformation and have been extensively reworked by later fault movements (cf. Evans and Kean, 1987). Alternatively, they may have developed during late Paleozoic transcurrent faulting. The prospects associated with ultramafic rocks such as those in the Baie Verte Peninsula and the GRUB line developed during or after middle Ordovician and later faulting and deformation. Other systems directly associated with granitic rocks (i.e., Cape Ray) may be Devonian. It is possible that systems associated with Carboniferous and Mesozoic faulting may also be present. Characterization of the age of these gold systems could contribute significantly to our understanding of Appalachian tectonics.

It is evident that the gold rush in Newfoundland is just beginning, and that this summary may rapidly become obsolete. We hope it will prove useful in the near term as a guide to further prospecting.

ACKNOWLEDGMENTS

We are indebted to the exploration community for their success and for their insights to the geology of gold in Newfoundland. In particular, Geoff Thurlow of BP Mining has provided a great deal of information on Central Newfoundland. Dan MacInnis of Noranda, Colin McKenzie of BP Mining, Terrence McKillen of Westfield Minerals, Barry McHale of Tillicum Resources, and Vic French of Shear Exploration all contributed to the material presented above. Many others including Dave Barbour, Garth Graves, Dave Gower, Derek Wilton, and Brad Mercer led various field trips. Lawson Dickson, Brian O' Brien, Peter Davenport and John Hayes of the Department of Mines provided maps. D. Wilton, P. Davenport and S.P. Colman-Sadd suggested improvements to the manuscript.

REFERENCES

Berger, B.R. and Eimon, P.I.
1983: Conceptual models of epithermal silver-gold deposits. *In* Cameron Volume on Unconventional Mineral Deposits. *Edited by* W.C. Shanks. American Institute of Mining, Metallurgical and Petroleum Engineers, New York, pages 191-205.

Bird, J.M. and Dewey, J.F.
1970: Lithosphere plate−continental margin tectonics and the evolution of the Appalachian Orogen. Geological Society of America Bulletin, Volume 81, pages 1031-1060.

Blackwood, R.F.
1985: Geology of the Facheux Bay area (11P/9), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-4, 56 pages.

Bruneau, Y.
1984: Report on work done on Licence 2291 from May 30 to October 26, 1983. Labrador Mining and Exploration Company Limited. [12H/15 (827)].

Buisson, G. and Leblanc, M.
1986: Gold bearing listwaenites (carbonatized ultramafic rocks) in ophiolite complexes: *In* Metallogeny of Basic and Ultrabasic Rocks. *Edited by* J.M. Gallagher, R.A. Iscear, C.R. Neary and H.M. Prichard. London Institute of Mining and Metallurgy, pages 121-132.

Chorlton, L.
1978: The geology of the La Poile map area (11O/9), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 78-5, 14 pages.

1980: Geology of the La Poile River area (11O/16), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-3, 86 pages.

Clifford, J.A.
1986: A note on gold mineralization in County Tyrone. *In* Geology and Genesis of Mineral Deposits in Ireland. *Edited by* C.J. Andrew, R.W.A. Crowe, S. Finlay, W.M. Pennell and J.F. Pyne. Irish Association for Economic Geology, pages 45-48.

Coish, R.A., Hickey, R. and Frey, F.A.
1982: Rare earth element geochemistry of the Betts Cove ophiolite, Newfoundland: Complexities in ophiolite formation. Geochimica et Cosmichimica Acta, Volume 45, pages 2117-2134.

Colman-Sadd, S.P.
1980: Geology of south-central Newfoundland and evolution of the eastern margin of Iapetus. American Journal of Science, Volume 280, pages 991-1017.

Colman-Sadd, S.P. and Swinden, H.S.
1982: Geology and mineral potential of south-central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-8, 102 pages.

Colvine, A.C., Andrews, A.J., Cherry, M.E., Durocher, M.E., Fyon, A.J., Lavigne, M.J. Jr., MacDonald, A.J., Marmont, S., Poulsen, K.H., Springer, J.C. and Troop, D.G.
1984: An integrated model for the origin of Archean lode gold deposits. Ontario Geological Survey, Open File 5524, 98 pages.

Coyle, M. and Strong, D.F.
1987: Geology of the Springdale Group: A newly recognized epicontinental-type caldera in Newfoundland. Canadian Journal of Earth Sciences, Volume 24, pages 1135-1148.

Davenport, P.H. and McConnell, J.W.
In press: Lake sediment geochemistry in regional exploration for gold. Submitted to Prospecting in areas of Glaciated Terrane, Halifax.

Dean, P.L.
1978: The volcanic stratigraphy of Notre Dame Bay, Newfoundland. M.Sc. thesis. Memorial University of Newfoundland, St. John's, Newfoundland, 204 pages.

Dean, P.L., Swinden, H.S., O'Driscoll, C.F., Tuach, J. and Kean, B.F.
1985: Gold-bearing geological environments in Newfoundland. A paper presented to the Northwest Mining Association, 91st Annual Convention, Spokane, Washington, 24 pages.

Dickson, W.L.
This volume: Geology and mineralization in the Hungry Grove Pond (1M/14) map area, southeastern Newfoundland.

Duke, N.A. and Hutchinson, R.W.
1976: Geologic relationships between massive sulfide bodies and ophiolitic volcanic rocks near York Harbour, Newfoundland. Canadian Journal of Earth Science, Volume 11, pages 53-69.

Dunning, S.R. and Krogh, T.E.
1985: Geochronology of ophiolites of the Newfoundland Appalachians. Canadian Journal of Earth Sciences, Volume 22, pages 1659-1670.

Erdmer, P.
1986: Geology of the Long Range Inlier in the Sandy Lake map area, western Newfoundland. *In* Current Research, Part B, Geological Survey of Canada, Paper 86-1B, pages 19-29.

Evans, D.T.W. and Kean, B.F.
1987: Gold and massive sulphide mineralization in the Tulks Hill volcanics, Victoria Lake Group, Central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 103-112.

Gale, G.H.
1973: Basaltic komaiites and ocean floor type basalt from northeastern Newfoundland. Earth and Planetary Science Letters, Volume 18, pages 22-28.

Gower, D., Graves, G., Walker, S. and MacInnis, D.
In press: Lode gold mineralization at Deer Cove, Baie Verte Peninsula. *In* Field Trip Guide for Trip B.9., Geological Association of Canada, St. John's, Newfoundland.

Hayes, J.P., Dickson, W.L. and Tuach, J.
1987: Preliminary map, Newfoundland granitoid rocks: Nomenclature, distribution and possible classification. Newfoundland Department of Mines, Open File 1636 and Open File Map 87-85.

Hibbard, J.
1983: Geology of the Baie Verte Peninsula, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Memoir 2, 279 pages.

Huard, A. and O'Driscoll, C.
1985: Auriferous specularite-alunite-pyrophyllite deposits of the Hickeys Pond area, Northern Burin Peninsula, Newfoundland. *In* Current Research, 1985, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 182-189.

1986: Epithermal gold mineralization in late Precambrian volcanic rocks on the Burin Peninsula. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 65-78.

Hurley, T.D. and Crocket, J.H.
1985: A gold-sphalerite association in a volcanogenic base-metal-sulphide deposit near Tilt Cove, Newfoundland. Canadian Mineralogist, Volume 23, pages 423-430.

Hutchinson, R.W.
1973: Volcanogenic sulphide deposits and their metallogenic significance. Economic Geology, Volume 68, pages 1223-1247.

Hyde, R.S.
1979: Geology of carboniferous strata in portions of the Deer Lake Basin, western Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 79-6, 43 pages.

International Impala Resources Limited
1987: News Release to the Vancouver Stock Exchange, October 6.

International Wildcat Resources Limited
1987: News Release to the Vancouver Stock Exchange, October 5.

Kay, A. and Strong, D.F.
1983: Geologic and fluid controls on As-Sb-Au mineralization in the Moreton's Harbour area, Newfoundland. Economic Geology, Volume 78, pages 1590-1604.

Kean, B.F.
1983: Geology and mineral deposits of the Lushs Bight Group in the Little Bay Head—Hall's Bay Head area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 157-174.

1984: Geology and mineral deposits of the Lushs Bight Group, Notre Dame Bay, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-1, pages 141-156.

Kean, B.F. and Evans, D.T.N.
This volume: Regional metallogeny of the Victoria Lake Group.

Kean, B.F., and Jayasinghe, N.R.
1981: Geology of the Badger map area (12A/16), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-2, 29 pages.

Keen, C.E., Keen, M.J., Nicols, B., Reid, I., Stockmal, G.S., Colman-Sadd, S.P., O'Brien, S.J., Miller, H., Quinlan, G., Williams, H. and Wright, J.
1986: Deep seismic reflection profile across the northern Appalachians. Geology, Volume 14, pages 141-145.

Kennedy, M.J., Phillips, W.E.D. and Neale, E.R.W.
1972: Similarities in the early structural development of the northwestern margin of the Newfoundland Appalachians and Irish Caledonides. 24th International Geological Congress, Montreal, Report, Section 3, pages 516-531.

Kirkham, R.V.
1987: Buchans Geology, Newfoundland. Geological Survey of Canada, Paper 86-24, 288 pages.

Knight, I.
1987: Geology of the Roddickton (121/16) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 343-357.

Kusmirski, R. and Norman, R.
1982: Geology between Tilt Cove and East Pond, east Burlington Peninsula. Licence numbers 1810-1812, 12241-12242, 1807, 12261. Newmont Exploration of Canada Limited. [2E/13 (434)].

Landfeld, L.A. and Silberman, M.L.
1987: Geology and geochemistry of the Mother Lode gold belt, California, compared with Archean lode gold deposits. *In* Bulk Mineable Precious Metal Deposits of the Western United States. *Edited by* J.L. Johnson. Geological Society of Nevada, 1987 symposium, pages 213-222.

McGillivray, G.
1985: Change Islands project—report on geological, geochemical and ground geophysical surveys. Licence 2500. [2E/9 (537)].

McHale, K.B.
1985: Report on exploration activities, Kim Lake area, project 403 (for Westfield Minerals), Tillicum Resources Limited, Unpublished report, 94 pages. [2D/3 (152)]

McHale, K.B. and McKillen, T.N.
1986: The Little River Project, south central Newfoundland. 1986 exploration activities, Westfield Minerals Limited, Unpublished report, 18 pages. [Nfld. (1502)]

McKenzie, C.B.
1986: Geology and mineralization of the Chetwynd deposit, southeastern Newfoundland, Canada. *In* Proceedings of Gold 86, an International Symposium on the Geology of Gold. *Edited by* A.J. MacDonald, pages 137-148.

1987: The Rattling Brook Project: An exploration update. Presented to Newfoundland Branch, CIM, November 5, 1987. [12H/15 (953)].

Mitchell, A.H.G. and Garson, M.S.
1976: Mineralization of plate boundaries. Minerals Science and Engineering, Volume 8, pages 253-287.

Morris, J.H.
1987: International reports: Ireland. Newsletter of International Liaison Group on Gold Mineralization, Number 4, pages 3-4.

Nesbitt, B.E., Murowchick, J.B. and Muelenbachs, K.
1986: Dual origin of lode gold deposits in the Canadian Cordillera. Geology, Volume 14, pages 506-509.

Newfoundland Department of Mines
1987: Call for proposals on exempt mineral lands. The Rambler Properties, Baie Verte Peninsula, Newfoundland. [12H/16 (757)]

O'Brien, B.H.
1987: The lithostratigraphy and structure of the Grand Bruit–Cinq Cerf area (parts of NTS areas 110/9 and 110/10), southwestern Newfoundland. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 87-1, pages 311-334.

O'Brien, S.J.
1987: Geology of the Eastport (west half) map area, Bonavista Bay, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 257-270.

O'Brien, S.J., Wardle, R.J. and King, A.F.
1983: The Avalon Zone: A Pan-African terrane in the Appalachian Orogen of Canada. Geological Journal, Volume 18, pages 195-222.

O'Driscoll, C.F and Tuach, J.
1987: Duffs granophyre and Foxtrap pyrophyllite mine: Hydrothermal fluids and epithermal ore deposits. Field guide for 1987 Mines Ministers Conference. Newfoundland Department of Mines, Mineral Development Division, Open File Report 1N (476).

O'Neill, P.
1987: Geology of the west half of the Weir's Pond (2E/1) map area. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 87-1, pages 271-286.

This volume: Geology of the east half of the Weir's Pond (2E/1) map area and its regional significance.

Papezik, V.S., Keats, H.F. and Vahtra, J.
1976: Geology of the Foxtrap pyrophyllite deposit, Avalon Peninsula, Newfoundland. Canadian Institute of Mining and Metallurgy Bulletin, Volume 7, pages 152-160.

Saunders, C.M.
1985: Controls of mineralization in the Betts Cove ophiolite. Unpublished M.Sc. thesis, Memorial University, St. John's, Newfoundland, 200 pages.

Saunders, C.M. and Tuach, J.
This volume: K-feldspathization, albitization and gold mineralization in granitoid rocks: the Rattling Brook alteration system, western White Bay, Newfoundland.

Schmidt, R.G.
1983: High-alumina hydrothermal systems in volcanic rocks and their significance to mineral prospecting in the Carolina State belt, United States Department of the Interior, Geological Survey, Open File 83-793, 46 pages.

Spence, W.H., Worthington, J.E., Jones, E.M. and Kitt, I.T.
1980: Origin of the gold mineralization at the Haile Mine, Lancaster County, South Carolina. Mining Engineering, January 1980, pages 70-72.

Stockmal, G.S., Colman-Sadd, S.P., Keen, C.E., O'Brien, S.J. and Quinlan, G.
1987: Collision along an irregular margin: a regional plate tectonic interpretation of the Canadian Appalachians. Canadian Journal of Earth Sciences, Volume 24, pages 1098-1107.

Strong, D.F.
1980: Granitoid rocks and associated mineral deposits of Eastern Canada and western Europe. *In* The Continental Crust and its Mineral Deposits. *Edited by* D.W. Strangway. Geological Association of Canada, Special Paper 20, pages 741-769.

1984: Geological relationships of alteration and mineralization at Tilt Cove, Newfoundland. *In* Mineral Deposits of Newfoundland—A 1984 Perspective. *Edited by* H.S. Swinden. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 84-3, pages 81-90.

Strong, D.F. and Payne, J.G.
1973: Early Paleozoic volcanism and metamorphism of the Moreton's Harbour—Twillingate area, Newfoundland. Canadian Journal of Earth Sciences, Volume 10, pages 1363-1379.

Strong, D.F. and Williams, H.
1972: Early Paleozoic flood basalts of northwest Newfoundland: their petrology and tectonic significance. Geological Association of Canada, Proceedings, Volume 24, pages 43-54.

Strong, D.F., Dickson, W.L., O'Driscoll, C.F. and Kean, B.F.
1974: Geochemistry of eastern Newfoundland granitoid rocks. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 74-3, 140 pages.

Swinden, H.S.
1981: Economic geology of the western Hermitage Flexure. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-1, pages 80-95.

1984: The Chetwynd Prospect, southwestern Newfoundland. Department of Mines and Energy, Mineral Development Division, Open File 11O/9 (148).

1988: Ordovician volcanism and mineralization in the Wild Bight Group, central Newfoundland; a geological, petrological, geochemical and isotopic study. Unpublished Ph.D. thesis, Memorial University of Newfoundland, 452 pages.

Swinden, H.S. and Strong, D.F.
1976: A comparison of plate tectonic models of metallogenesis in the Appalachians, the North American Cordillera and the east Australian Paleozoic. Geological Association of Canada, Special Paper 14, pages 443-471.

Swinden, H.S. and Kean, B.F.
1984: Volcanogenic sulfide mineralization in the Newfoundland Central Mobile Belt. *In* Mineral Deposits of Newfoundland—A 1984 Perspective. *Compiled by* H.S. Swinden. Canadian Institute of Mining and Metallurgy Guidebook, pages 55-77.

In press: Geological setting and mineral deposits of the Dunnage Zone, Newfoundland. Field Trip Guidebook, Mineral Deposits Section, Geological Association of Canada, 1988 Annual Meeting, St. John's, Newfoundland.

Swinden, H.S. and Sacks, P.E.
1986: Stratigraphy and economic geology of the southern Roberts Arm Group, central Newfoundland. *In* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, pages 213-220.

Swinden, H.S. and Thorpe, R.I.
1984: Variation in style of volcanism and massive sulfide deposition in early to middle Ordovician island-arc sequences of the Newfoundland Central Mobile Belt. Economic Geology, Volume 79, pages 1596-1619.

Thurlow, J.G.
1973: Lithogeochemical studies in the vicinity of the Buchans massive sulphide deposits, central Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, 171 pages.

Thurlow, J.G. and Swanson, E.A.
1981: Geology and ore deposits of the Buchans area, central Newfoundland. *In* The Buchans Orebodies: Fifty Years of Geology and Mining. *Edited by* E.A. Swanson, D.F. Strong and J.G. Thurlow. Geological Association of Canada, Special Paper 22, pages 113-142.

Tuach, J.

1986: Metallogeny of Newfoundland granites—studies in the western White Bay area and on the southwest coast. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 27-38.

1987a: List of gold occurrences and deposits in Newfoundland. Accompanied by brief descriptions, source references and a reduced version of Map 87-04, (Open File Nfld 1510) 36 pages.

1987b: Mineralized environments, metallogenesis, and the Doucers Valley fault complex, western White Bay: A philosophy for gold exploration in Newfoundland. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 87-1, pages 129-144.

Tuach, J. and French, V.A.

1986: Gold mineralization of possible late Precambrian age in the Jackson's Arm area (12H/15), White Bay, Newfoundland. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 39-49.

Tuach, J. and Kennedy, M.J.

1978: The geologic setting of the Ming and other sulfide deposits, Consolidated Rambler Mines, northeast Newfoundland. Economic Geology, Volume 73, pages 192-206.

Upadhyay, H.D. and Strong, D.F.

1973: Geological setting of the Betts Cove copper deposits, Newfoundland: an example of ophiolite mineralization. Economic Geology, Volume 68, pages 161-167.

Weir, R.H., Jr. and Kerrick, D.M.

1987: Mineralogic, fluid inclusion and stable isotope studies of several gold mines in the Mother Lode, Tuolumne and Mariposa Counties, California. Economic Geology, Volume 82, pages 328-344.

Williams, H.

1978: Geological development of the northern Appalachians: its bearing on the evolution of the British Isles. *In* Crustal Evolution in Northwestern Britain and Adjacent Regions. *Edited by* D.L. Bowes and B.E. Leake. Geological Journal, Special Issue 10, pages 1-22.

1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 16, pages 792-807.

Williams, H. and Hatcher, R.D., Jr.

1982: Suspect terranes and accretionary history of the Appalachian orogen. Geology, Volume 10, pages 530-536.

Williams, H. and Stevens, R.K.

1974: The ancient continental margin of eastern North America. *In* The Geology of the Continental Margins. *Edited by* C.A. Burk and C.L. Drake. Springer-Verlag, New York, pages 781-796.

Wilton, D.H.C.

1984: Metallogenic, tectonic and geochemical evolution of the Cape Ray Fault Zone, with emphasis on electrum mineralization. Unpublished Ph.D. thesis, Memorial University of Newfoundland, 618 pages.

Wilton, D.H.C. and Strong, D.F.

1986: Granite-related gold mineralization in the Cape Ray Fault Zone of southwestern Newfoundland. Economic Geology, Volume 81, pages 281-295.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines
Mineral Development Division, Report 88-1, pages 307-317

K-FELDSPATHIZATION, ALBITIZATION AND GOLD MINERALIZATION IN GRANITOID ROCKS: THE RATTLING BROOK ALTERATION SYSTEM WESTERN WHITE BAY, NEWFOUNDLAND

C.M. Saunders and J. Tuach
Mineral Deposits Section

ABSTRACT

Auriferous fracture stockworks, veins and shear zones are developed in Proterozoic granitoid rocks of the Rattling Brook area. Alteration of the precursor foliated tonalite–granodiorite occurred during the Paleozoic in at least two main stages. Stage 1 alteration (K-feldspathization) is variably developed over an area of about 2 km^2, and consists of microcline and sericite formed by reaction of plagioclase and mafic minerals with hydrothermal fluids. Stage 2 alteration (albitization) is restricted to stockwork fractures, veins and vein selvages, and overprints both stage 1 alteration and unaltered rock. It consists of microcrystalline to fine grained albite, with lesser amounts of quartz, ankerite and sericite. Both alteration episodes are considered to be part of the same mineralization process, which resulted in precipitation of pyrite, arsenopyrite and gold. Fluids with high $K+$ activity initially permeated along grain boundaries and converted the host to granite. Subsequent hydraulic fracturing was accompanied by an increase in the activity of $Na+$, resulting in albitization and deposition of sulphides and gold.

INTRODUCTION

Auriferous fracture stockworks, veins and shear zones are developed in K-feldspathized granitoid rocks over an area of approximately 2 km^2 near Rattling Brook (Figure 1) in the Jackson's Arm area of western White Bay. Descriptions of the gold mineralization have been presented by Bruneau (1984) and McKenzie (1987). Field descriptions of the geology and geological setting have been presented by Tuach and French (1986) and Tuach (1987).

Mineralization is predominantly hosted by a Proterozoic, megacrystic, foliated granitoid rock from which zircon separates have been dated at around 1042 Ma (Erdmer, 1986). Recent work by BP-Selco geologists has shown that gold mineralization also occurs in Eocambrian to Early Cambrian quartzites that unconformably overly the granitoid-hosted mineralization, and in limestones overlying the quartzites (McKenzie, 1987).

The name 'Apsy pluton' (after Apsy Pond, Figure 1) is tentatively proposed for these Proterozoic granitoid rocks. Sample locations and general geology are shown in Figure 1.

The hydrothermally altered and mineralized rocks around Rattling Brook (Figure 2) are here referred to as the Rattling Brook alteration zone. In the northern part of the alteration zone, the host rock has been converted from a tonalite–granodiorite to a granite *(sensu stricto)* by reaction of hydrothermal fluids with plagioclase and mafic minerals to form microcline and sericite. Subsequent fracture stockworks, veins and local areas of hydrothermal breccia contain albite and lesser amounts of quartz, ankerite and sericite. This report documents the observed petrographic and geochemical characteristics of the Rattling Brook alteration zone.

PETROGRAPHY

Host Rocks

The Apsy pluton is composed of plagioclase and K-feldspar megacrysts set in a groundmass of biotite, and local hornblende, intergrown with abundant sphene, ilmenite, apatite and lesser zircon. Deformation of the pluton has resulted in a planar S-fabric and an augen texture.

Saussuritized plagioclase commonly forms anhedral grains of less than 0.5 cm in diameter, but locally it forms megacrysts up to 2 cm long. K-feldspar forms finely perthitic megacrysts up to 3 cm long that locally exhibit fine-scale microcline twinning.

Hornblende is present in several samples from the western part of the area (Figure 1). It is partly replaced by biotite, which in turn is partly replaced by chlorite and epidote. The distribution of the mafic mineral assemblages indicates increasing retrogressive metamorphism toward the east, in agreement with regional metamorphic patterns described by Erdmer (1986).

Small, pink, microcline-rich, granitic bodies cut the above lithologies, and are interpreted to be late differentiated phases of the Apsy pluton.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

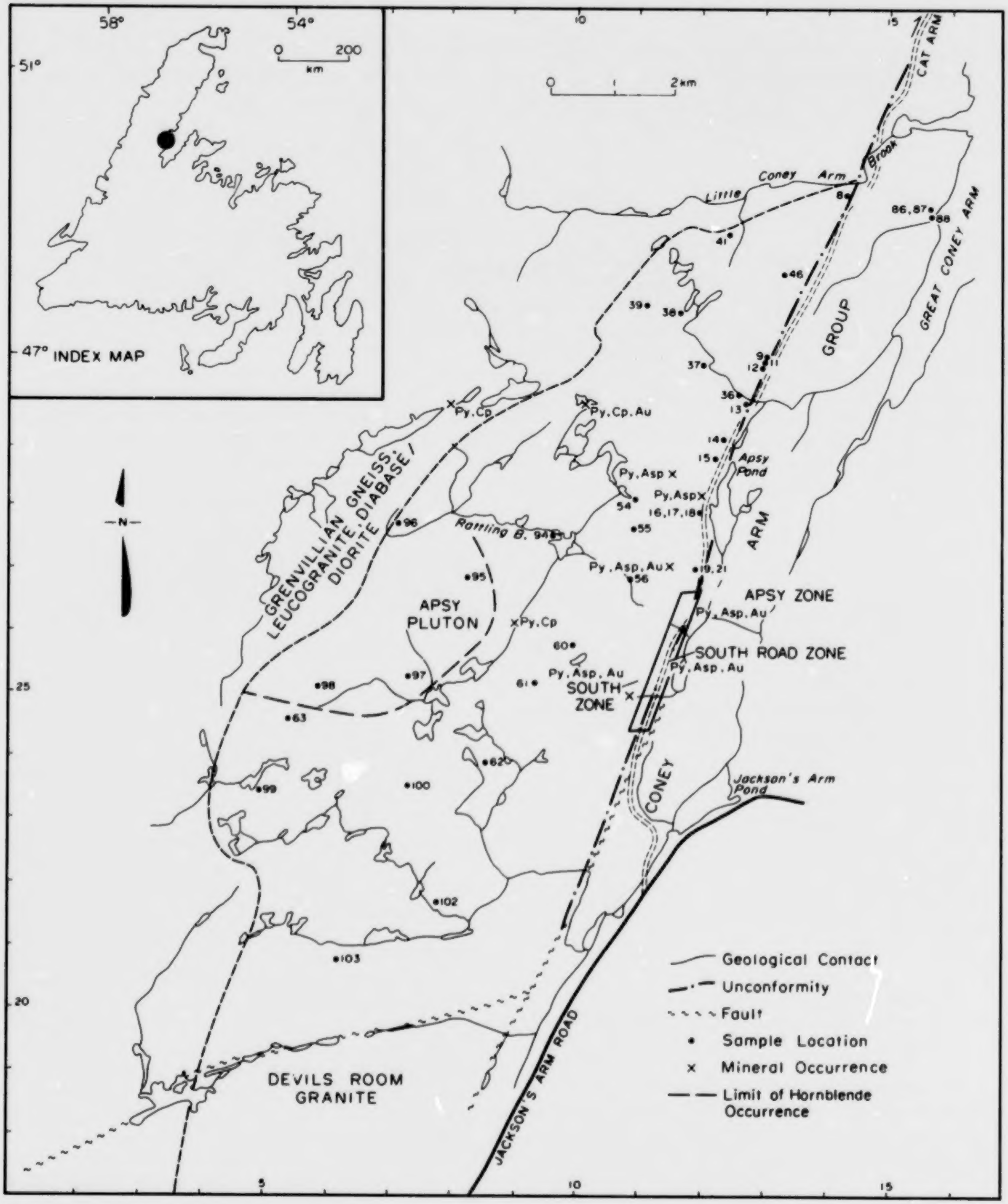
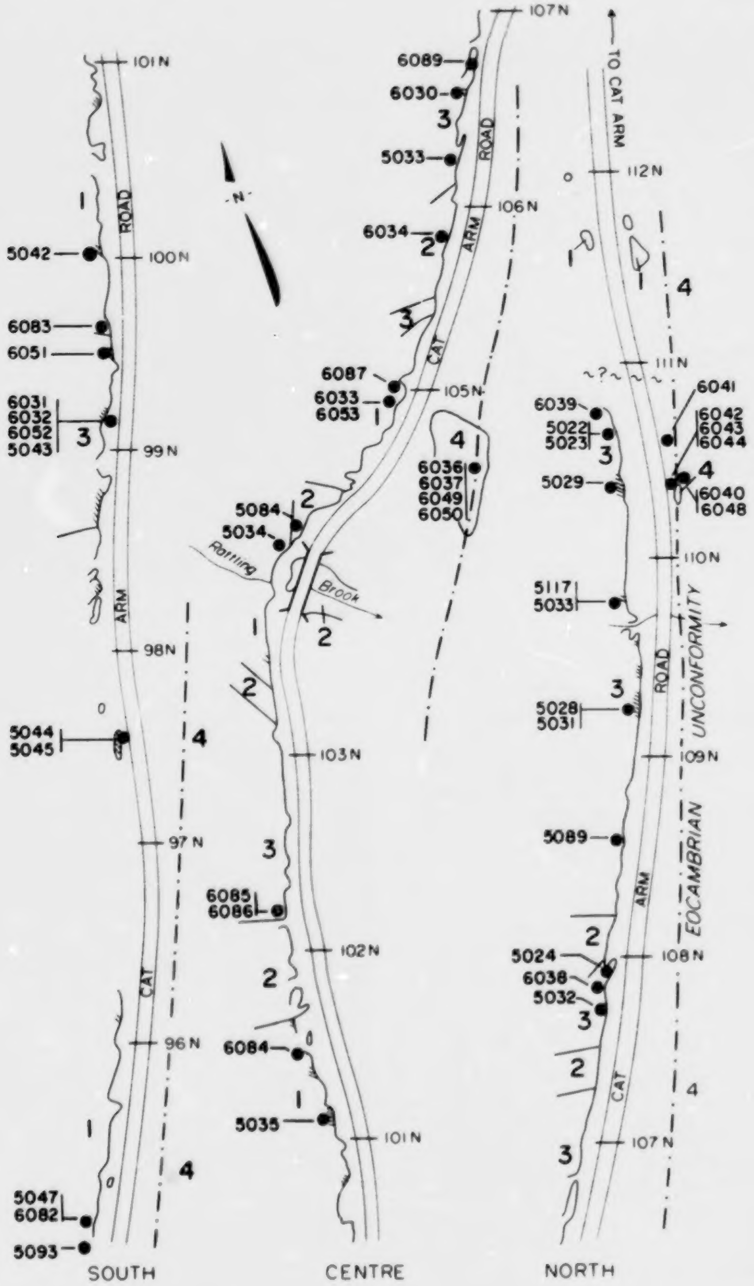

58°
54°
51°
47° INDEX MAP
0 200 km
0 1 2 km
10
15
5
25
20
CAT ARM
Brook
Little Coney Arm
GREAT CONEY ARM
GROUP
ARM
CONEY
Apsy Pond
Jackson's Arm Pond
Rattling B.
GRENVILLIAN GNEISS, LEUCOGRANITE, DIABASE / DIORITE
APSY PLUTON
DEVILS ROOM GRANITE
APSY ZONE
SOUTH ROAD ZONE
SOUTH ZONE
JACKSON'S ARM ROAD
Py, Cp
Py, Cp, Au
Py, Asp
Py, Asp
Py, Asp, Au
Py, Cp
Py, Asp, Au
Py, Asp, Au
Py, Asp, Au
N
8
86, 87
88
41
46
39
38
37
9
12
11
36
13
14
15
54
16, 17, 18
55
96
94
95
19, 21
56
60
97
98
61
63
62
99
100
102
103
Geological Contact
Unconformity
Fault
Sample Location
Mineral Occurrence
Limit of Hornblende Occurrence

Figure 1. *General geology and sample locations in the Rattling Brook area. The area shown in the box is enlarged in Figure 2. Numbers along map border are UTM co-ordinates. Py–pyrite; Cp–chalcopyrite; Asp–arsenopyrite; Au–gold.*



101N
100N
99N
98N
97N
96N
CAT ARM ROAD
5042
6083
6051
6031
6032
6052
5043
5044
5045
5047
6082
5093
N
6089
6030
5033
6034
6087
6033
6053
5084
5034
Rattling Brook
6036
6037
6049
6050
6085
6086
6084
5035
107N
106N
105N
103N
102N
101N
TO CAT ARM
112N
111N
110N
109N
108N
107N
6039
5022
5023
5029
6041
6042
6043
6044
6040
6048
5117
5033
5028
5031
5089
5024
6038
5032
EOCAMBRIAN UNCONFORMITY
1
2
3
4
SOUTH
CENTRE
NORTH

LOWER PALEOZOIC

Coney Arm Group

4 *quartzite overlain by phyllite, limestone.*

UPPER PROTEROZOIC

3 *Granite–K-Feldspathized; abundant fracture stockworks*

UPPER PROTEROZOIC *(Continued)*

2 *Granodiorite–granite; insipient alteration*

1 *Granodiorite; relatively unaltered*

SYMBOLS

— — — *Unconformity*

〜 ⊂⊃ *Outcrop ridge, individual outcrop*

\\\\\\\\ *Area of anomalous Au (most >1 g/t)*

Figure 2. *Geological sketch of the Rattling Brook alteration zone along the Cat Arm Road (modified from Bruneau, 1984) showing area of detailed sampling. Grid is marked in 100-m intervals.*

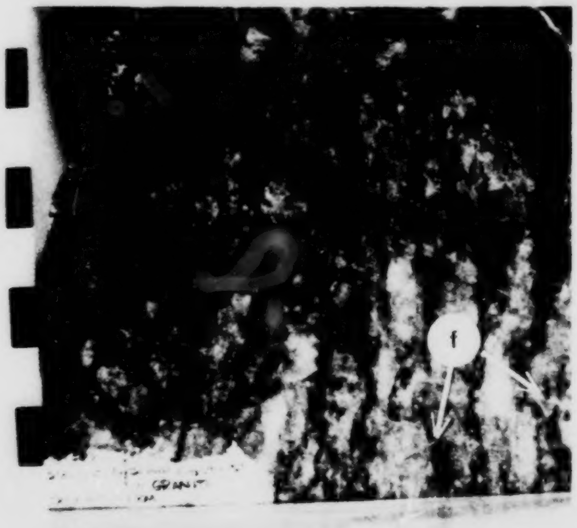


Plate 1. *Slab of typical stage 1 microcline-rich granite. Rock is cut by sheeted microfractures (f). Dark rectangles on scale are 1 cm long.*

Microcline Alteration Zone

In the vicinity of mineralization, the host rock has been altered to a foliated, bright pink, leucocratic granite (Plate 1) that grades imperceptably into more typical unaltered tonalite–granodiorite of the Apsy pluton.

The alteration assemblage consists mostly of K-feldspar and quartz, with subordinate amounts of albitic plagioclase and sericite. Commonly, feldspar megacrysts are internally recrystallized, and are composed of uniform subgrains characterized by sharp boundaries and well-developed triple-point junctions (Plate 2). Generally, the K-feldspar has poorly developed to well-developed, fine-scale microcline twinning and is commonly perthitic. Locally, albite rims surround individual microcline grains. The groundmass to the megacrysts is composed of sericite, rutile, carbonate, zircon and apatite. Biotite, chlorite and epidote are minor or absent, and up to 10 percent pyrite and arsenopyrite are locally intergrown with the matrix assemblage.

Albite Veins and Alteration

The foliated pink granite is locally cut by fracture and veinlet stockworks that contain fine grained to microcrystalline albite, quartz, carbonate and sericite (Plate 3). This assemblage also occurs in the matrix of small areas of mineralized hydrothermal breccia (Plate 4). Albite partly replaces wall-rock microcline and plagioclase over a width of less than 3 cm marginal to fractures (Plate 5). Swarms of sheeted microcrystalline albite veins occur locally over widths ranging from 10 to 20 cm (Plate 3) to 12 m; the intervening country rock is pervasively replaced by albite. On the basis of field observations, Tuach and French (1986) misidentified the microcrystalline albite and quartz assemblage as fine grained silica.

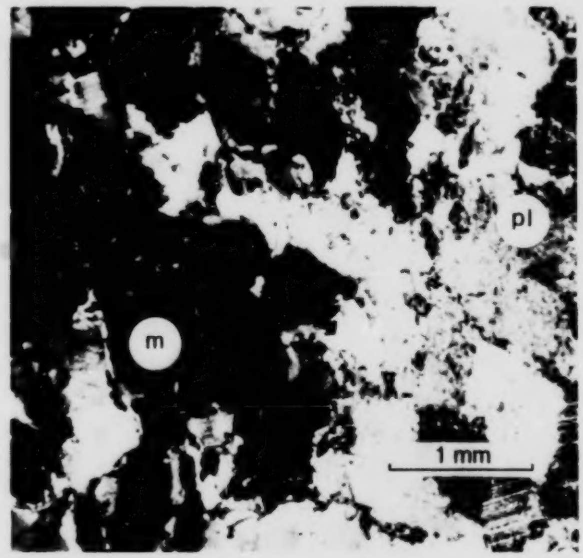


Plate 2. *Polygonal texture of plagioclase (pl) and microcline (m) in stage 1 altered granite. Crossed-nicols photomicrograph of sample 7045024.*

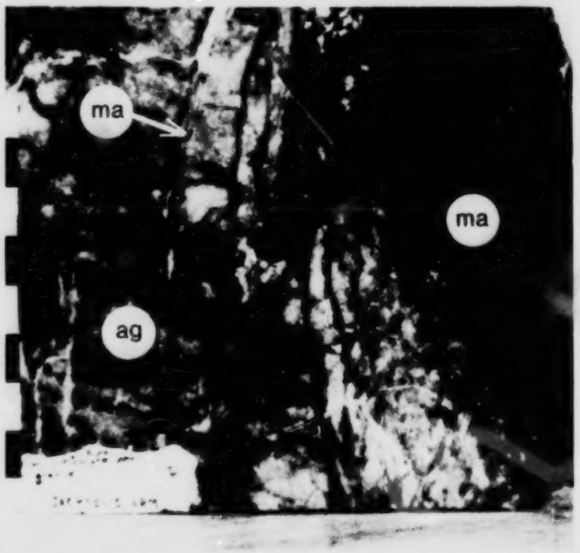


Plate 3. *Slab of albitized granite (ag) cut by microcrystalline albite (ma) veins (stage 2). Dark rectangles on scale are 1 cm long.*

Carbonate is also found locally in veins and in the matrix of hydrothermal breccias. Electron-microprobe analyses show that the composition of the carbonate varies from ferroan dolomite to ankerite; the latter is most common. Coarse grained siderite and ankerite have been identified in a sample from a 10-cm-wide gold and sulphide-bearing carbonate–sericite vein. Rare euhedral quartz crystals in this vein contain trails of secondary or pseudosecondary aqueous-CO_2 inclusions.

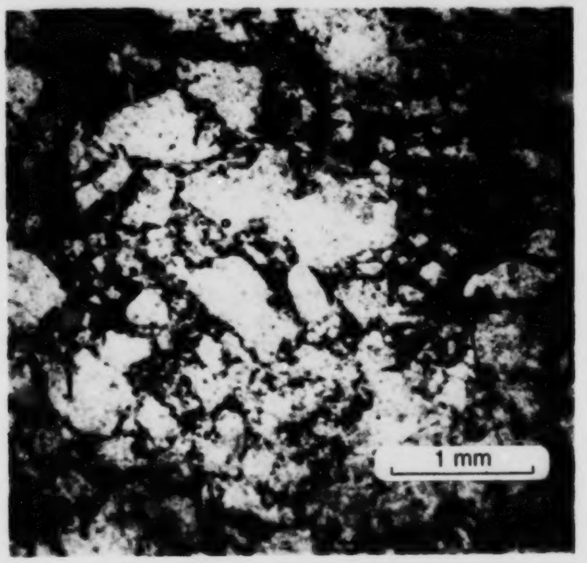


Plate 4. *Hydrothermal breccia consisting of microcline and albite fragments in a matrix of crushed rock fragments and microcrystalline albite, carbonate and pyrite (stage 2). Opaque material is partly pyrite and partly intergrown rutile and leucoxene. Plane light photomicrograph of sample 7046112.*

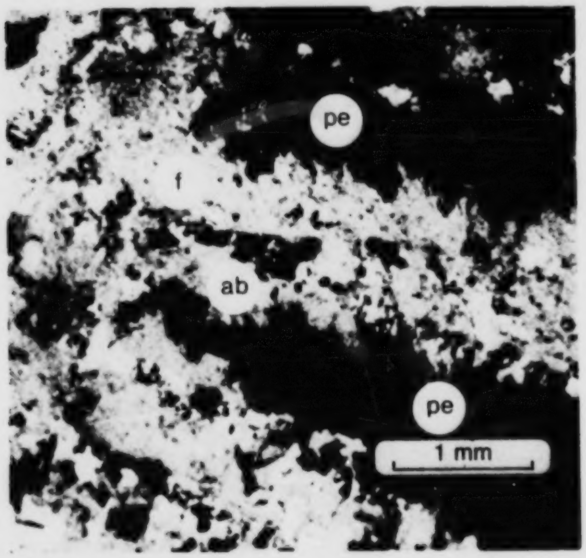


Plate 5. *Stage 2 untwinned hydrothermal albite (ab) replaces perthite (pe) marginal to fractures (f). The fractures are lined by fine grained, twinned albite. Crossed-nichols photomicrograph of sample 7045029.*

Sulphide Minerals

The K-feldspathized and albitized granites locally contain up to 10 percent disseminated sulphides. Pyrite and arsenopyrite crystals are commonly arranged along the foliation of the granite, but are completely undeformed. The sulphides are intergrown with biotite and/or sericite and other accessory minerals. An assemblage of finely intergrown pyrite (± arsenopyrite), carbonate, rutile (intergrown with leucoxene), apatite and zircon is present in the most altered samples.

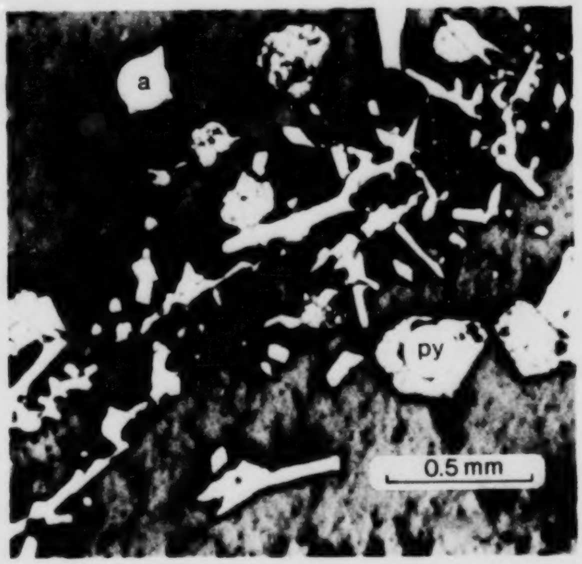


Plate 6. *Euhedral arsenopyrite (a) and pyrite (py) line fractures in siderite–ankerite vein. Reflected-light photomicrograph of sample 7046034.*

The albite–quartz–ankerite–sericite veins contain up to 10 percent sulphides; the sulphides consist mainly of pyrite and arsenopyrite, but there are rare occurrences of chalcopyrite (Plate 6). Arsenopyrite occurs as delicate, euhedral undeformed crystals that commonly have hollow cores. Pyrrhotite and galena occur as inclusions in pyrite and arsenopyrite. Gold has been observed in two thin sections from samples that are cut by swarms of microcrystalline albite veins. The gold occurs as clusters of less than one to greater than fifteen micrometre inclusions in pyrite (Plate 7). SEM analyses indicate only traces of silver in the gold. Rare, extremely fine grained (less than one micrometre) Au-Ag telluride, Pb-Au telluride and Pb telluride were observed as inclusions in pyrite in one sample.

PARAGENESIS

Alteration related to the mineralizing system appears to have occurred in two main stages. Stage 1 alteration (K-feldspathization) involved conversion of the precursor foliated tonalite–granodiorite to a granite *(sensu stricto)* by metasomatic reaction of hydrothermal fluids with plagioclase and mafic minerals. Much of the plagioclase and the mafic minerals were converted to K-feldspar and sericite. Analysis of remnant plagioclase by electron microprobe shows that it is albite. Sericite replaced biotite, chlorite and epidote. Ilmenite was replaced by rutile, and sphene was converted

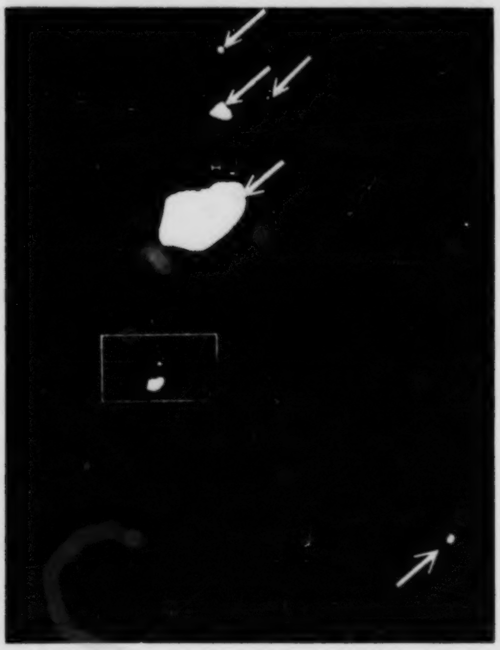


Plate 7. *Scanning-electron photomicrograph showing gold (arrows) included in pyrite (grey). Scale bar (length represents 60 micrometres) applies to lower half of photo. The top half (area in box) is enlarged by a factor of 5 with respect to the bottom half. The largest gold grain is 6 micrometres across. Sample 7046032.*

to rutile and calcite. The zircon and apatite are apparently unaltered.

Stage 2 alteration (albitization) is restricted to stockwork fractures, veins and vein selvages, and overprints both microcline-rich stage 1 alteration and the unaltered rock. Microcrystalline to fine grained albite, and lesser amounts of quartz, ankerite and sericite were deposited as veins that partly replaced the wall rock. Precipitation of pyrite, arsenopyrite and gold accompanied this alteration event.

The sulphides are concentrated along the foliation of the host granite, but are themselves undeformed, indicating that mineralization postdated deformation. Pyrite, and to a lesser extent arsenopyrite, are intergrown with and partly replace ilmenite, sphene and rutile. The titanium oxides, which are concentrated along the foliation of the host granite, may have acted as preferential nucleation sites for the formation of the sulphides.

GEOCHEMISTRY

Introduction

The rock samples can be separated into altered and unaltered groups, although there is a continuum between the two. Unaltered rocks are those in which distinct chemical and petrological features related to the mineralizing event are minor or absent; they have, however, been affected by regional retrogressive metamorphic events. Most samples of unaltered rock are from the tonalite–granodiorite, but three are from small granitic bodies interpreted to be late differentiated phases of the Apsy pluton.

The altered rocks can be separated into two groups dominated by either stage 1 alteration (microcline-rich granites) or stage 2 alteration (albite-rich rocks). The albitic samples contain vein material and albitized granite wall rock (Plate 3) in varying proportions. The microcline-rich granites that are enriched in Au (greater than 100 ppb) are separated from those containing less than 10 ppb (Figures 3 to 6). All the albite-rich samples are enriched in gold.

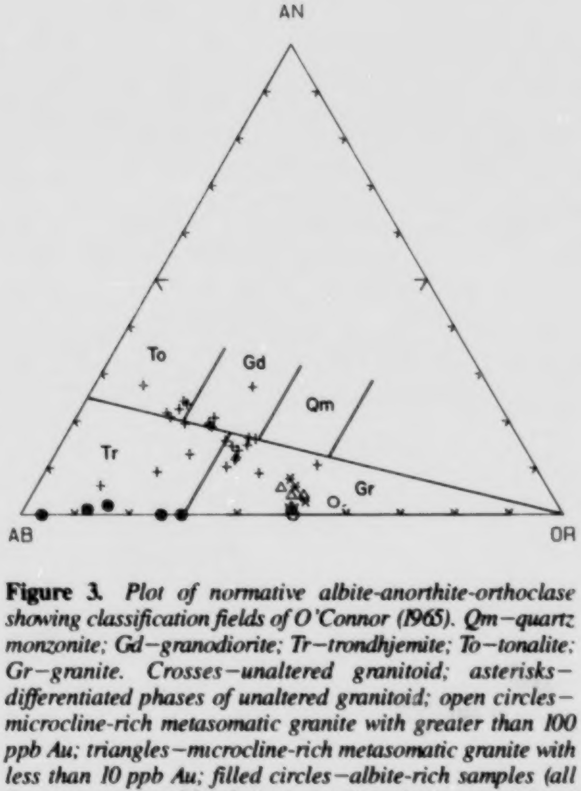


Figure 3. *Plot of normative albite-anorthite-orthoclase showing classification fields of O'Connor (1965). Qm–quartz monzonite; Gd–granodiorite; Tr–trondhjemite; To–tonalite; Gr–granite. Crosses–unaltered granitoid; asterisks–differentiated phases of unaltered granitoid; open circles–microcline-rich metasomatic granite with greater than 100 ppb Au; triangles–microcline-rich metasomatic granite with less than 10 ppb Au; filled circles–albite-rich samples (all have greater than 30 ppb Au) consisting of vein-material and albitized granite wall rock.*

Results

Unaltered rocks from the Apsy pluton have compositions that straddle the tonalite, trondhjemite, granodiorite and granite fields on O'Connor's (1965) normative Ab-An-Or classification diagram (Figure 3). The variation may be a result of fractionation processes and regional alteration, but coarse grained granites present geochemical sampling problems that could explain part of the variation. Late phases of the pluton plot in the granite field. Average compositions of samples from the Apsy pluton are given in Table 1.

Table 1. Average analyses of samples from the Apsy pluton and the Rattling Brook alteration zone

	HOST		GRANITOID		ALTERED ± MINERALIZED ROCKS					MISCELLANEOUS						
	Mafic to Intermediate		Granite Differentiate		Microcline Granite		Albitic Granite and Veins		Sulphide Carbonate Vein	Biotite Schlieren	Amphibolite Xenocryst	Amphibolite Xenocryst	Long Range Dyke	Diabase Dyke	Diabase Dyke	Felsite Dyke
	$\bar{x}$	$\bar{s}$	$\bar{x}$	$\bar{s}$	$\bar{x}$	$\bar{s}$	$\bar{x}$	$\bar{s}$								
	n = 26*		n = 3*		n = 11*		n = 5*		n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1
Oxide (wt.%)																
SiO_2	63.06	3.96	71.65	0.91	70.27	4.17	65.46	3.21	35.15	40.90	59.85	59.00	45.80	46.80	43.85	74.60
TiO_2	1.13	0.39	0.35	0.02	0.36	0.10	0.97	0.21	0.22	4.88	1.64	1.47	1.38	1.47	1.38	0.11
Al_2O_3	14.87	0.71	13.79	0.23	13.58	1.29	13.73	0.97	8.23	9.30	13.92	12.89	16.54	16.27	16.18	13.01
FeO(T)	5.51	1.59	1.48	0.31	2.27	0.79	4.71	0.87	11.63	19.16	8.42	6.49	8.69	8.49	8.04	0.42
MnO	0.09	0.03	0.03	0.01	0.03	0.02	0.04	0.02	0.28	0.42	0.10	0.14	0.17	0.17	0.15	0.01
MgO	1.43	0.43	0.35	0.10	0.39	0.15	0.57	0.33	6.09	4.99	1.31	2.27	9.20	7.84	7.21	0.03
CaO	3.31	1.04	1.07	0.19	0.72	0.38	0.95	0.45	9.77	6.16	3.83	3.73	10.83	8.92	8.62	0.09
Na_2O	3.83	0.61	3.51	0.22	3.23	0.22	5.84	0.89	0.14	0.03	3.05	3.87	2.13	2.77	2.10	2.99
K_2O	3.80	0.72	5.85	0.46	6.32	1.38	2.59	1.17	4.00	5.15	3.65	4.62	0.88	1.61	1.63	7.04
P_2O_5	0.39	0.17	0.08	0.03	0.10	0.06	0.32	0.12	0.14	1.91	0.77	0.53	0.06	0.20	0.13	0.02
LOI	1.36	0.50	1.15	0.01	1.84	0.84	3.42	0.94	14.02	3.02	1.49	3.93	3.38	3.75	10.01	0.72
Element (g/t)																
Li	22	7	11	2	14	4	19	11	18	106	25	32	30	n.d.	51	8
F	792	229	235	94	246	64	304	328	n.d.	2121	887	n.d.	117	415	141	26
V	66	22	30	4	16	5	44	12	17	258	69	51	201	n.d.	216	8
Cr	7	3	4	1	5	5	4	1	4	20	4	5	206	n.d.	161	4
Ni	4	8	2	1	2	4	1	0	5	4	1	1	83	n.d.	56	4
Cu	6	3	4	3	15	28	12	8	17	22	7	6	62	n.d.	49	3
Zn	102	39	27	5	22	7	45	23	13	423	147	190	73	n.d.	76	9
Ga	23	5	15	2	15	4	20	1	21	40	27	19	18	19	18	13
Rb	90	22	88	17	172	41	51	28	119	221	85	84	28	n.d.	73	149
Sr	365	95	196	52	113	36	119	38	73	102	400	310	236	n.d.	402	70
Y	47	10	12	5	18	6	17	6	22	183	78	52	26	30	23	2
Zr	129	36	98	36	170	30	81	17	124	272	46	91	113	160	102	84
Nb	20	5	5	3	12	3	16	5	3	86	29	30	1	4	2	1
Mo	3	1	2	0	3	2	4	2	12	8	5	4	4	n.d.	4	3
Ag	0.1	0.0	0.1	0.0	0.4	0.8	0.6	0.6	1.1	0.1	1.0	0.1	0.1	n.d.	0.1	0.1
Ba	1305	314	1754	730	873	367	851	409	492	441	1170	1400	355	n.d.	506	398
La	71	19	87	106	87	39	75	42	105	233	88	113	5	15	9	9
Ce	143	36	139	171	171	72	152	85	197	549	192	234	15	43	21	6
Pb	13	3	12	1	29	52	19	24	13	1	9	8	1	n.d.	6	10
Th	4	2	12	14	14	7	6	11	5	3	2	1	1	3	1	4
Element (mg/t)																
Au	1	2	1	0	480	794	1819	805	4550	3	1	183	1	57	1	1

* For FeO(T) n (number of samples) = 26, 3, 8, and 5 respectively; for F, n = 24, 3, 9 and 3 respectively; n.d. = not determined; $\bar{x}$ = mean; $\bar{s}$ = standard deviation

The microcline-rich samples (stage 1) plot in the granite field as expected (Figure 3). The albite-rich samples (stage 2) plot in the trondhjemite field. Average compositions of both groups are given in Table 1.

The two groups of altered granites differ from each other mainly in their K_2O, Na_2O and SiO_2 contents (Table 1 and Figure 4). When compared to the unaltered rocks, both groups show lower average contents of CaO, MgO, MnO, Al_2O_3, Sr and to a lesser extent Zn (Table 1 and Figure 4).

The microcline-rich granites have generally high Rb, La, Ce, Th and Zr (Table 1 and Figure 4) compared to the albite-rich samples, which generally have low levels of these elements. Late differentiates of the Apsy pluton can be separated from the microcline-rich altered granites by significantly lower Rb and slightly higher Sr. Two of the late differentiates have low La, Th and Ce but one sample has anomalously higher concentrations of these elements. The microcline-rich granites do not differ significantly from the differentiates in concentrations of elements such as Li, F, Mo, and Cu. The albite-rich samples have slightly higher concentrations of Cu and variable, but not significantly different, concentrations of Li, F, and Mo.

Microcline-rich granites have significantly lower Ba/K_2O ratios than either unaltered granitoid or albite-rich granite (Figure 5). Electron-microprobe analyses of perthitic and microcline-twinned K-feldspar from a variety of samples reveal that K-feldspar in the unaltered rocks and the albite-rich granites contain an average of 0.66 percent BaO (Table 2). In the microcline-rich granites, K-feldspar contains an average of 0.16 percent BaO.

Gold is anomalously high in the albite-rich samples and in many of the microcline-rich samples (Figure 4). The highest gold value was obtained from a 10-cm-wide pyrite–arsenopyrite-bearing siderite–ankerite–sericite vein. An

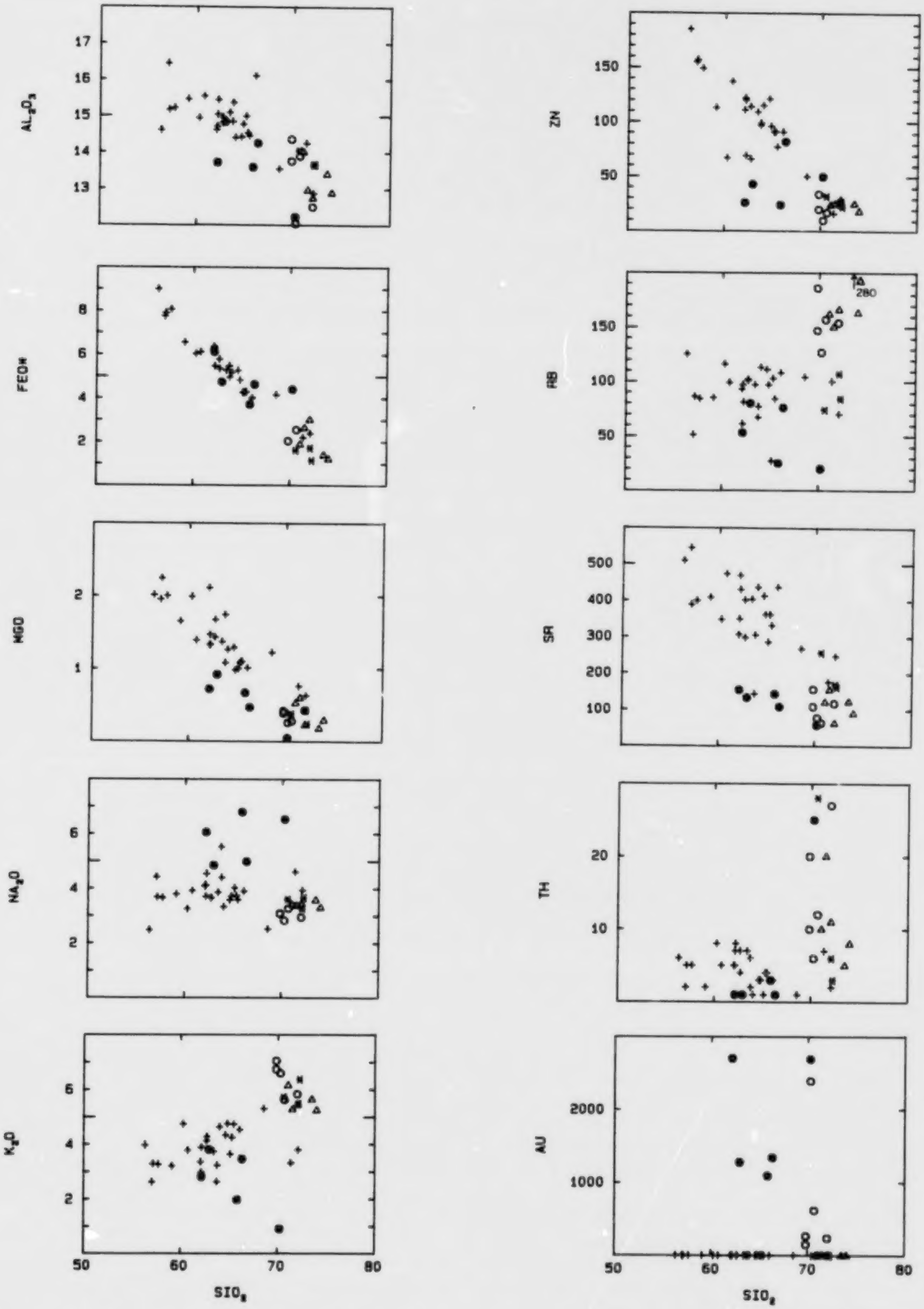


Figure 4. *Harker diagrams showing variation of selected major and trace elements. Symbols as for Figure 1. Oxides in percent, trace elements in ppm, gold in mg/t. Explanation given in text.*

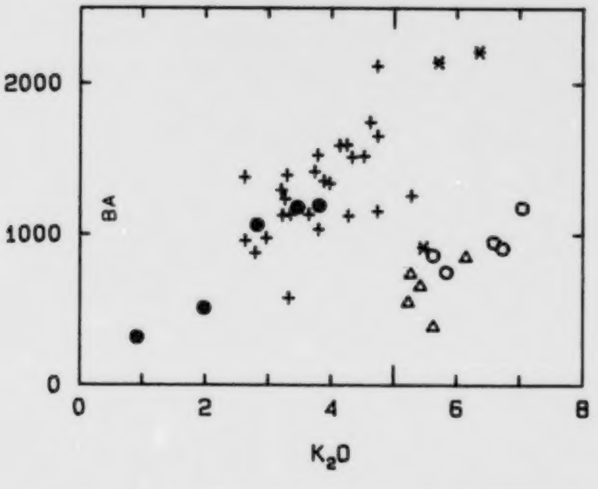


Figure 5. *Plot of Ba against K_2O. Note lower Ba/K_2O ratios of microcline-rich metasomatic granites. Symbols as for Figure 1.*

Table 2. BaO content of K-feldspar

Rock Type	% BaO	No. Points	No. Samples
Unaltered	0.67	13	3
Differentiates	0.35	6	2
Albite-rich	0.66	13	4
Microcline-rich	0.16	19	5

amphibolite inclusion and a cross-cutting diabase dyke also contain anomalous gold (Table 1).

Interpretation

The chemical composition of the altered samples reflects their mineralogy. Microcline-rich granites are enriched in K_2O and Rb and albite-rich samples are enriched in Na_2O. The net loss of CaO, Sr and Zn from both the albite-rich and microcline-rich granites results from replacement of plagioclase. In addition, MgO and MnO have been removed from the rocks during formation of sericite and carbonate from mafic minerals.

Although the altered samples are pyritic, there has been little net addition of iron (Figures 4 and 6). This suggests that sulphur and arsenic reacted with iron from ilmenite, biotite, chlorite and epidote in the host rock to form pyrite and arsenopyrite in the altered rock.

Microcline-rich granites have lower Ba/K_2O ratios than the unaltered rocks or albite-rich granites. This results from the significantly lower Ba content of the metasomatic microcline. The presence of Ba-rich microcline in the albite-rich granites indicates that albitization overprints unaltered granite as well as granite that was affected by stage 1 (low-Ba microcline) alteration.

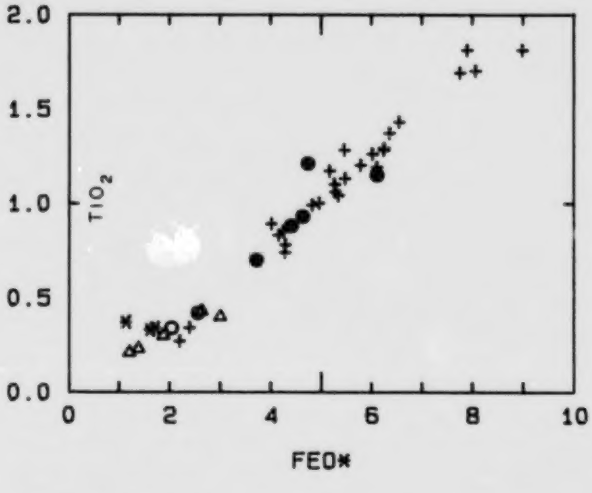


Figure 6. *Plot of TiO_2 against FeO(total). Note that there has been little net addition of iron to the mineralized and altered samples. Symbols as for Figure 1.*

DISCUSSION

K-feldspathization of the granitoid rocks in the Rattling Brook area clearly predated the formation of albite veins and mineralization. It is possible that stage 1 alteration accompanied or predated Grenvillian deformation (ca. 1000 Ma), and is unrelated to the mineralized albite stockworks. However, the spatial association of stage 1 and stage 2 alteration assemblages, and the implication that two different alteration systems of different ages were superimposed argues against such an interpretation.

Gold mineralization and alteration extend up into Lower Cambrian rocks (McKenzie, 1987) demonstrating that the hydrothermal system was Lower Cambrian or younger. Euhedral outlines of silicate and sulphide crystals in stockworks indicate that growth of these phases postdated major deformation in the area and, in turn, suggests that the stockwork system is Late Silurian or younger.

It is probable that the alteration is related to a single hydrothermal system and that variations observed are due to temporal and spatial changes in fluid composition and ion activity in response to changing physical parameters (cf. Beane, 1982). Initially, fluids with high K+ activity permeated along grain boundaries and crystal dislocations. Rupturing of the system, perhaps in response to increasing fluid pressure, led to local hydraulic fracturing, and was accompanied by an increase in Na+ activity and the formation of albite, sulphides and gold in and around fractures.

Hydrothermal K-feldspar and albite have been documented at other gold deposits (cf. Berger and Eimon, 1983; Colvine *et al.*, 1984), and also in association with many of the major granite-related stockwork (porphyry) deposits (White *et al.*, 1981; Beane, 1982). In Newfoundland, pervasive albite alteration occurs at the Windowglass Hill gold prospect at Cape Ray (Wilton, 1984; Tuach, 1986), and the presence of sodium-rich rocks in the Baggs Hill granite near gold occurrences at Big Pond suggests albitization accompanied gold mineralization (Tuach, 1986).

The Siluro-Devonian Devils Room granite, which is in fault contact with the Apsy pluton (Figure 1), may have provided a heat source and/or a source of fluids to the mineralizing system. However, a marked lack of enrichment of elements such as F, Li, Cu and Mo in rocks of the Rattling Brook alteration zone argues against a granitic source of fluids. It is also possible that cross-cutting mafic dykes provided a heat source for hydrothermal activity.

The fluids appear to have been enriched in CO_2, S, As, Na, K and Au. Buisson and Leblanc (1986) suggest Cl-bearing fluids of similar composition were responsible for enrichment of gold associated with carbonatized ultramafic rocks (listwaenites). Such fluids are assumed to be seawater derived and related to serpentinization of underlying ultramafic rocks. The gold is assumed to have been leached from the ultramafic rocks. The similarity of fluid compositions could mean a similar origin for gold mineralization in the Rattling Brook area. The slight enrichment of Rb, La, Ce and Th in the microcline-rich granites may be the result of local remobilization of these elements.

CONCLUSIONS

Alteration related to gold mineralization in the Rattling Brook hydrothermal system developed in two main stages. Stage 1 involved large-scale conversion of the precursor foliated tonalite–granodiorite to granite *(sensu stricto)* via potassium metasomatism. Plagioclase and the mafic silicates were converted to K-feldspar and sericite. Ilmenite was replaced by rutile, and sphene was converted to rutile and calcite.

Stage 2 alteration is restricted to stockwork fractures, veins and vein selvages, and overprints both microline-rich, stage 1 alteration and unaltered granitoid rocks. Deposition of albite, quartz, ankerite and sericite was accompanied by pyrite, arsenopyrite and gold mineralization.

Samples affected dominantly by stage 1 alteration are enriched in K_2O, slightly enriched in Rb, La, Ce and Th and depleted in CaO, Al_2O_3, MgO, MnO, Sr and Zn. Those affected dominantly by stage 2 alteration are depleted in all the above elements and are strongly enriched in Na_2O.

The presence of similar mineralization in Lower Cambrian quartzites and limestones above the granitoid rocks (McKenzie, 1987) indicates that mineralization is Lower Cambrian or later. Lack of deformation of alteration and ore assemblages in fractures suggests that the bulk of the mineralization post-dated the Acadian deformation in the area and is Late Silurian or younger.

ACKNOWLEDGMENTS

Andy Kerr and Derek Wilton are thanked for critically reading the manuscript and offering suggestions for its improvement. Andy Kerr, John Hayes and Jim Butler are thanked for help with plotting programs and computer-aided data manipulation.

REFERENCES

Beane, R.E.
1982: Hydrothermal alteration in silicate rocks–southwestern North America. *In* Advances in Geology of the Porphyry Copper Deposits, Southwestern North America. *Edited by* S.R. Titley. University of Arizona Press, pages 117-137.

Berger, B.R. and Eimon, P.I.
1983: Conceptual models of epithermal silver-gold deposits. *In* Cameron Volume on Unconventional Mineral Deposits. *Edited by* W.C. Shanks. American Institute of Mining, Metallurgical and Petroleum Engineers, New York, pages 191-205.

Bruneau, Y.
1984: Report on work done on Licence 2291 from May 30 to October 26, 1983. Labrador Mining and Exploration Company Limited. [12H/15(827)]

Buisson, G. and Leblanc, M.
1986: Gold-bearing listwaenites (carbonatized ultramafic rocks) from ophiolite complexes. *In* Metallogeny of basic and ultrabasic rocks. *Edited by* J.M. Gallagher, R.A. Iscer, C.R. Neary and H.M. Prichard. Institute of Mining and Metallurgy, London, pages 121-131.

Colvine, A.C., Andrews, A.J., Cherry, M.E., Durocher, M.E., Fyon, A.J., Lavigne, M.F. Jr., Macdonald, A.J., Marmont, S., Poulsen, K.H., Springer, J.C. and Troop, D.G.
1984: An integrated model for the origin of Archean lode gold deposits. Ontario Geological Survey, Open File 5524, 98 pages.

Erdmer, P.
1986: Geology of the Long Range Inlier in the Sandy Lake map area, western Newfoundland. *In* Current Research, Part B. Geological Survey of Canada, Paper 86-1B, pages 19-29.

McKenzie, C.B.
1987: The Rattling Brook project: An exploration update. Unpublished manuscript presented to the Newfoundland Branch, Canadian Institute of Mining and Metallurgy, Nov. 5, 1987. Newfoundland Department of Mines, Mineral Development Division, Open File 12H/15(953), 12 pages.

O'Connor, J.T.
1965: A classification for quartz-rich igneous rocks based on feldspar ratios. United States Geological Survey Professional Paper 525-B, pages B79-B84.

Tuach, J. and French, V.A.
1986: Gold mineralization of possible late Precambrian age in the Jackson's Arm area (12H/15), White Bay, Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 39-49.

Tuach, J.
1986: Metallogeny of Newfoundland granites—studies in the western White Bay area and on the southwest coast. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 27-38.

1987: Mineralized environments, metallogenesis, and the Doucers Valley Fault Complex, western White Bay: A philosophy for gold exploration in Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 129-144.

White, W.H., Bookstrom, A.A., Kamilli, R.J., Ganster, M.W., Smith, R.P., Ranta, D.E. and Steininger, R.C.
1981: Character and origin of Climax-type molybdenum deposits. Economic Geology, Seventy-Fifth Anniversary Volume, pages 270-316.

Wilton, D.H.C.
1984: Metallogenic, tectonic and geochemical evolution of the Cape Ray Fault Zone, with emphasis on electrum mineralization. Unpublished Ph.D. thesis, Memorial University of Newfoundland, 618 pages.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 319-330

REGIONAL METALLOGENY OF THE VICTORIA LAKE GROUP

B.F. Kean and D.T.W. Evans
Mineral Deposits Section

ABSTRACT

The Victoria Lake Group is a structurally complex assemblage of volcanic-flow, pyroclastic, volcaniclastic and sedimentary rocks. Initial age dates suggest two generations of volcanic sequences are present. They are represented by Cambro-Ordovician 'island-arc-tholeiite/ocean-floor basalt' volcanic rocks and by Llanvirn–Llandeillo 'calc-alkaline' mafic to andesitic flows.

The adjacent mafic volcanic sequences south of Red Indian Lake are all 'ocean-floor basalts' type and probably represent 'within-plate' volcanism.

Mineralization within the Victoria Lake Group consists of volcanogenic sulphides and epigenetic gold. The volcanogenic sulphide mineralization is hosted by both the 'tholeiitic' and 'calc-alkaline' sequences. Ti-rich basalts within the Victoria Lake Group, and sequences adjoining the Victoria Lake Group, are not known to contain massive sulphide mineralization.

The gold mineralization is hosted by a variety of rock types and probably has a large age range. Mineralizing styles or types appear to vary from epithermal to 'shear related' and may in most cases, be a combination of the two.

INTRODUCTION

The Victoria Lake Group (Kean, 1977) underlies that part of the Dunnage Zone (Williams, 1979) of central Newfoundland that extends from Grand Falls in the northeast to King George IV Lake in the southwest, and from Red Indian Lake in the north to Noel Paul's Brook in the south (Figure 1).

Access to the area is provided by woods roads from Millertown and Grand Falls. The area is characterized by a heavily forested, gently undulating topography covered by extensive glacial till. Consequently, bedrock exposure is poor except for Tulks Ridge, which extends from Tulks Valley to Victoria River.

Detailed studies of the Victoria Lake Group and adjoining sequences in central Newfoundland were begun in 1984. These studies involved regional rock-geochemical, paleontological, geochronological and metallogenic studies and detailed stratigraphic, structural and geochemical studies in the areas of known mineralization. A regional metallogenic compilation of the Central Mobile Belt in conjunction with the Geological Survey of Canada (H.S. Swinden) was begun in 1987. A brief description of the main showings and prospects is given in the appendix to this report. For detailed descriptions of the major massive sulphide and gold prospects in the Victoria Lake Group, the reader is referred to Kean (1985), Kean and Evans (1986) and Evans and Kean (1986, 1987). Significant new insights into the geology of the Victoria Lake Group and adjoining areas have been developed and preliminary results are herein presented.

GENERAL GEOLOGY

Kean (1977) proposed and defined the 'Victoria Lake Group' to include all pre-Caradocian volcanic and sedimentary rocks between Red Indian Lake and the Rogerson Lake Conglomerate (Figure 1).

The Victoria Lake Group is divided into two regional lithofacies (Kean and Jayasinghe 1980, 1982; Kean, 1985): 1) volcanic rocks in the southwest (Tulks Hill volcanics) and along the group's southeastern margin (Tally Pond volcanics), comprising approximately 60 percent of the group, and 2) a predominantly sedimentary facies in the northeast that is laterally equivalent to, and derived from, the volcanic rocks.

Both of the volcanic units are characterized by linear belts of predominantly felsic pyroclastic rocks. Mafic flows are common in the Tally Pond volcanics but minor in the Tulks Hill volcanics. In the latter, mafic volcanic rocks are mainly pyroclastic, comprising mafic to intermediate aquagene tuff, lapilli tuff, agglomerate and breccia.

The Tally Pond and Tulks Hill volcanic units represent the major products of volcanic activity with associated hydrothermal alteration and mineralization. Small intercalations or lenses of volcanic rocks (Valley Brook and

---

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

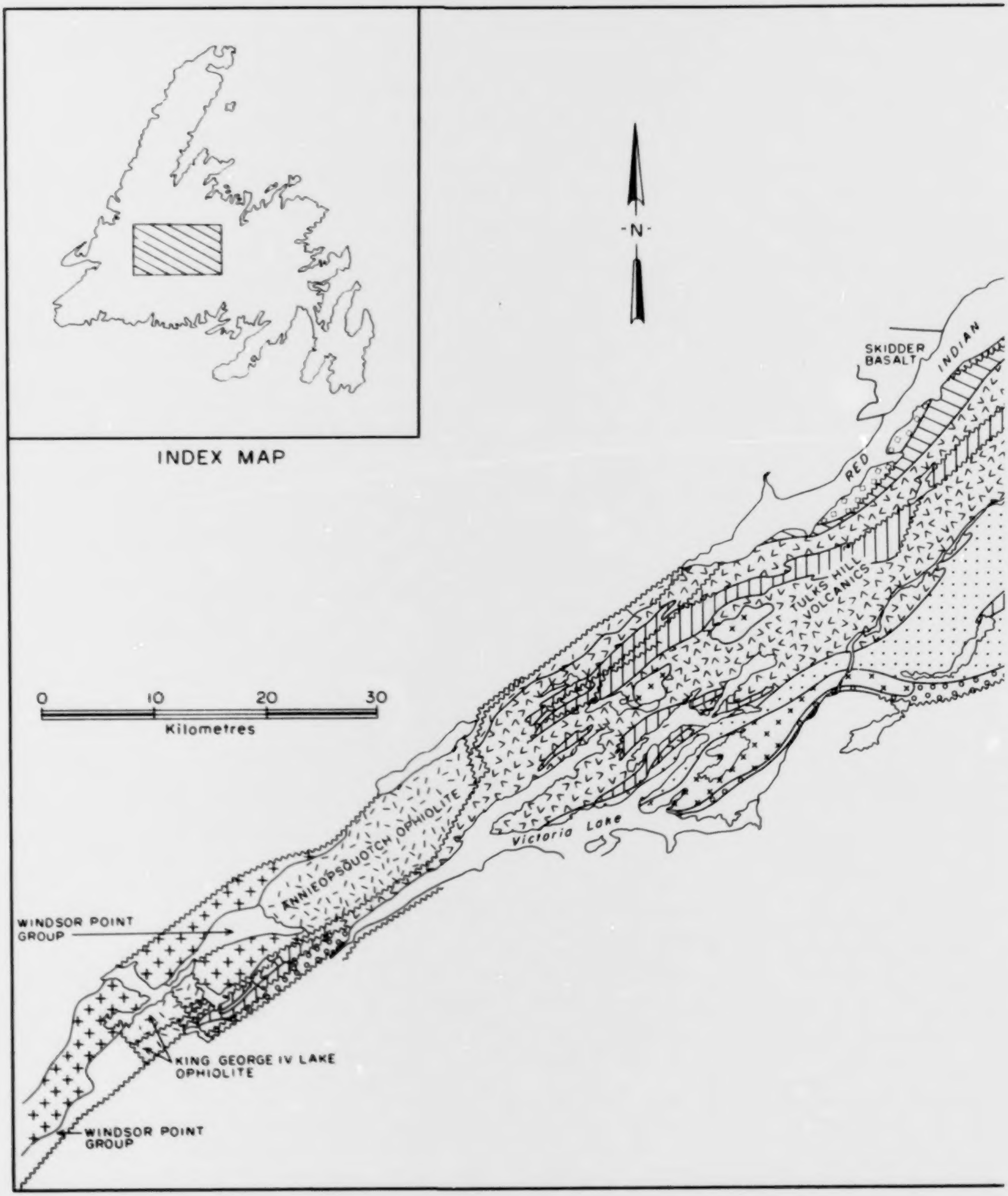
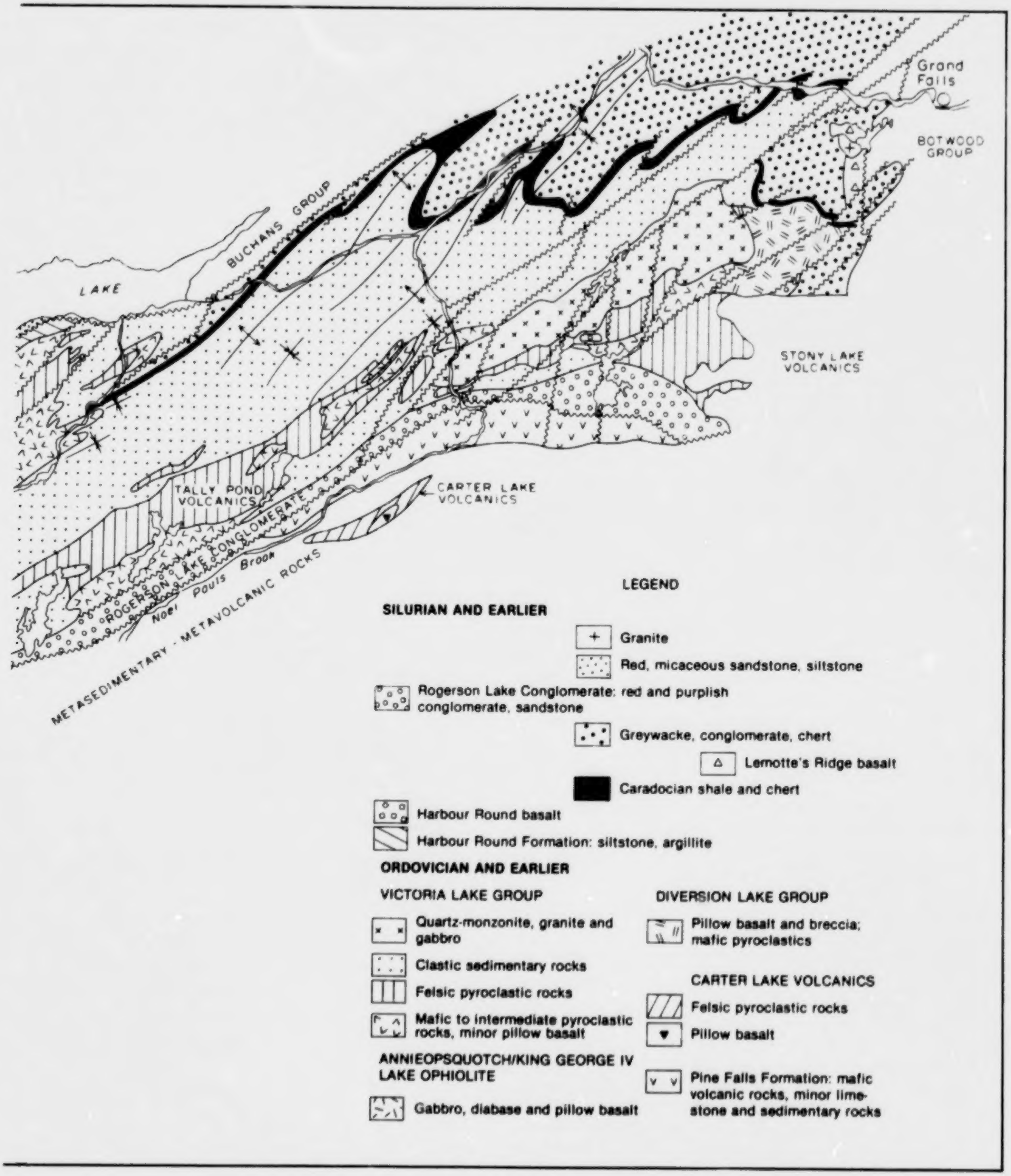

INDEX MAP
N
0
10
20
30
Kilometres
SKIDDER BASALT
RED INDIAN
TULKS HILL VOLCANICS
ANNIEOPSQUOTCH OPHIOLITE
Victoria Lake
WINDSOR POINT GROUP
KING GEORGE IV LAKE OPHIOLITE
WINDSOR POINT GROUP

Figure 1. *Simplified geological map of the Victoria Lake Group and adjoining sequences.*


Grand Falls
BOTWOOD GROUP
BUCHANS GROUP
LAKE
STONY LAKE VOLCANICS
TALLY POND VOLCANICS
CARTER LAKE VOLCANICS
ROGERSON LAKE CONGLOMERATE
Noel Pauls Brook
METASEDIMENTARY - METAVOLCANIC ROCKS
LEGEND
SILURIAN AND EARLIER
Granite
Red, micaceous sandstone, siltstone
Rogerson Lake Conglomerate: red and purplish conglomerate, sandstone
Greywacke, conglomerate, chert
Lemotte's Ridge basalt
Caradocian shale and chert
Harbour Round basalt
Harbour Round Formation: siltstone, argillite
ORDOVICIAN AND EARLIER
VICTORIA LAKE GROUP
Quartz-monzonite, granite and gabbro
Clastic sedimentary rocks
Felsic pyroclastic rocks
Mafic to intermediate pyroclastic rocks, minor pillow basalt
ANNIEOPSQUOTCH/KING GEORGE IV LAKE OPHIOLITE
Gabbro, diabase and pillow basalt
DIVERSION LAKE GROUP
Pillow basalt and breccia; mafic pyroclastics
CARTER LAKE VOLCANICS
Felsic pyroclastic rocks
Pillow basalt
Pine Falls Formation: mafic volcanic rocks, minor limestone and sedimentary rocks

Tom Joe Brook basalts) also occur within the sedimentary rocks of the Victoria Lake Group to the northeast.

Siliciclastic rocks constitute most of the northeastern sedimentary facies of the Victoria Lake Group (Kean and Jayasinghe, 1982). This facies consists of greywacke and interbedded siltstone, shale, argillite, conglomerate and rare limestone. Siliceous siltstone and chert are more common near the top of the sequence. The sedimentary facies is interpreted to be a shallowing-upward turbidite sequence.

Limestone lenses near the top of the sedimentary facies and near the northeast end of the Tulks Hill volcanics have yielded Late Llanvirn to Early Llandeilo conodonts (Kean and Jayasinghe, 1982). Dunning *et al.* (1987) obtained a U–Pb zircon age of 462 $^{+4}_{-2}$ Ma on a subvolcanic rhyolite at Victoria River, approximately 20 m stratigraphically below the fossil locality. Dunning (1986) reported a U–Pb zircon age of approximately 517 Ma for the Tally Pond volcanics.

The Victoria Lake Group is conformably overlain by the Harbour Round Formation and Caradocian chert and shale on its northern margin (Kean and Jayasinghe, 1980; 1982). It is unconformably overlain by the Rogerson Lake Conglomerate along its southeastern margin, although the contact is generally sheared and faulted. The linear, narrow outcrop pattern of the conglomerate and local clast provenance suggest it is a fault-scarp, molasse-type deposit; the original southern margin of the Victoria Lake Group was thus probably fault bounded.

Kean (1985) interpreted rocks of the Victoria Lake Group to occupy a regional northeast-trending anticlinorium (Victoria Anticlinorium). Regionally, the sequence dips steeply and faces northwesterly on the north limb and dips gently and faces southeasterly on the south limb; however, there are many first-order and second-order folds resulting in variable facing directions. A paucity of outcrop generally precludes detailed structural interpretations.

The Victoria Lake Group has an inhomogenously developed, regional penetrative foliation defined by chlorite, sericite, flattened clasts and crystal augen. The intensity of this foliation, which is subparallel to bedding and axial planar to tight and isoclinal folds, increases to the southwest. The rocks have been metamorphosed to the lower-greenschist facies, except locally along their southern margin where middle-greenschist to lower-amphibolite facies rocks are present.

Evans and Kean (1987) broadly discussed the mineralization within the Victoria Lake Group under two main groupings: (1) volcanogenic sulphide, and (2) epigenetic gold mineralization. They demonstrated that the volcanogenic mineralization is of both massive and disseminated stockwork type and is associated with variably altered felsic volcanic rocks. The gold mineralization occurs in a number of different geological environments, and may vary in age from Ordovician to Silurian.

REGIONAL STUDIES

A simplified version of the geological map for the Victoria Lake Group is presented in Figure 1. It is part of a new, 1:500,000-scale, metallogenic map of the Central Mobile Belt that is currently in preparation. This new map reflects our current knowledge of the geological evolution and paleotectonic setting of the Victoria Lake Group. Preliminary results from recent geochemical, geochronological and paleontological studies are presented in point form below.

1) Geochemical data (Figure 2) for mafic flows (Figure 3) indicate: (a) the mafic flows of the Tally Pond volcanics and those mafic flows of the Tulks Hill volcanics occurring along Harmsworth Steady (Victoria River) and associated with the major stratigraphic unit of felsic pyroclastic rocks plot (Figure 3) in the 'island-arc tholeiite'–'ocean-floor basalt'

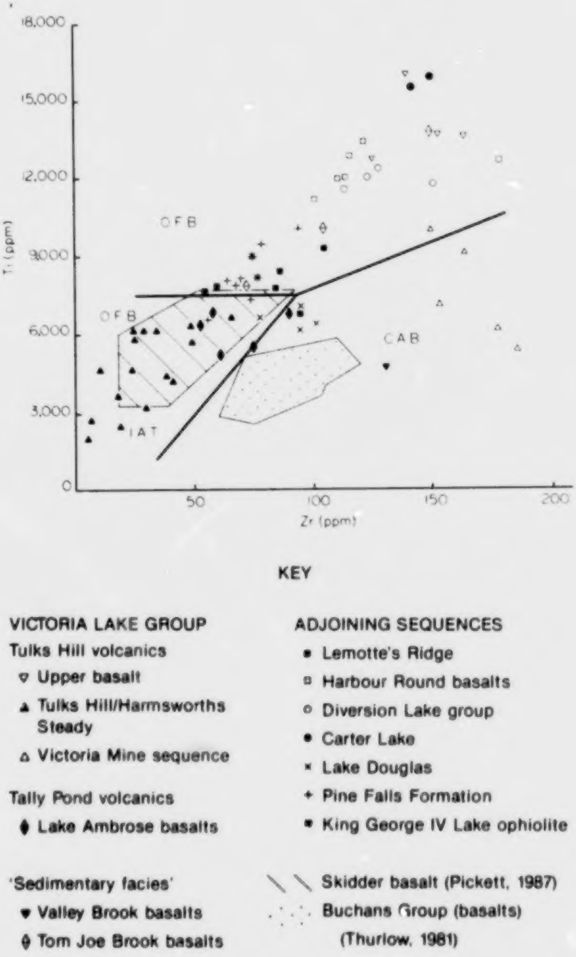


Figure 2. *Ti vs. Zr discriminant diagram for mafic volcanic rocks of the Victoria Lake Group and adjoining sequence. Fields after Garcia (1978): IAT–island-arc tholeiite; OFB–ocean-floor basalt; CAB–calc-alkaline basalt.*

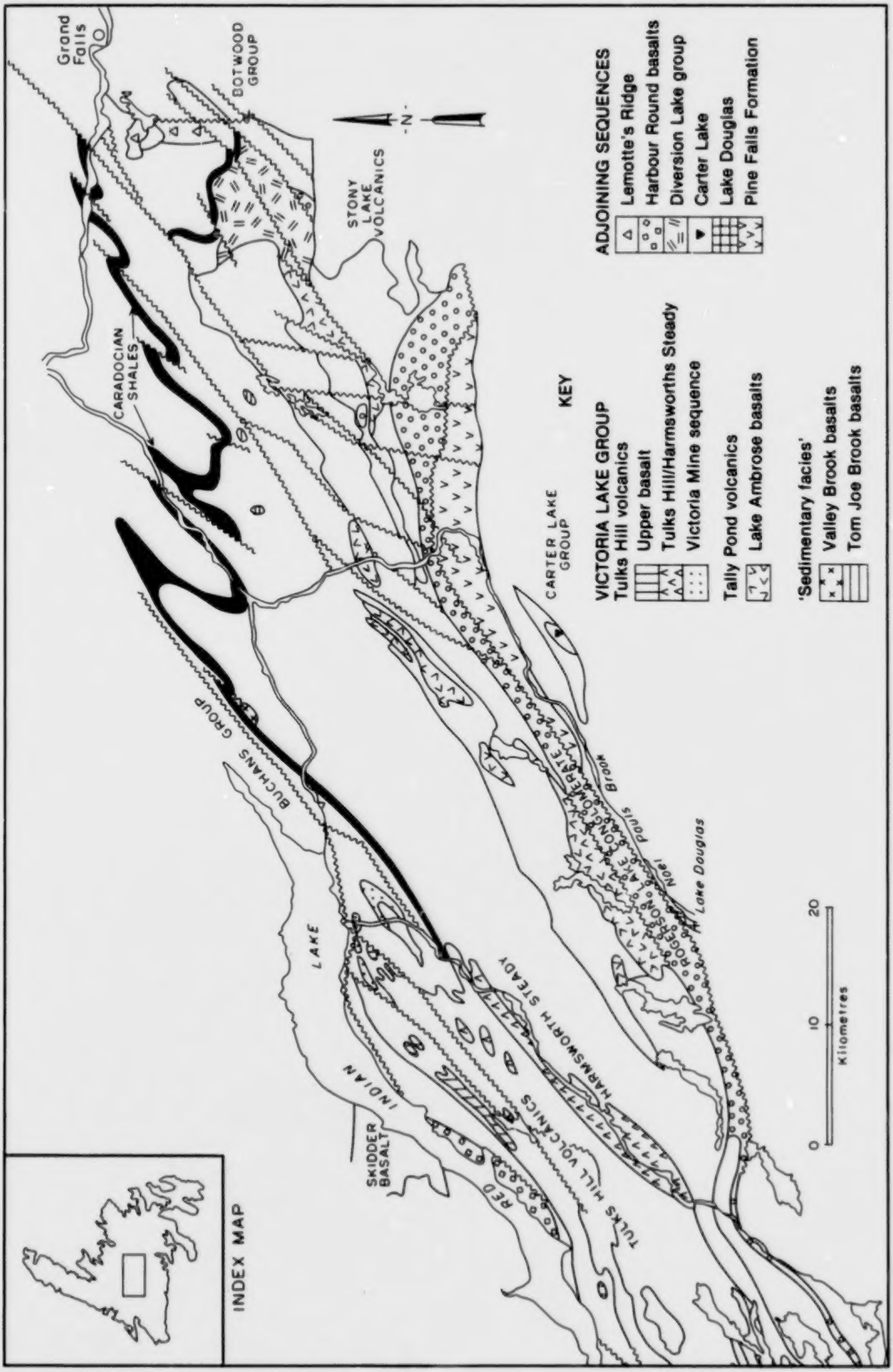

INDEX MAP
Grand Falls
BOTWOOD GROUP
STONY LAKE VOLCANICS
CARADOCIAN SHALES
CARTER LAKE GROUP
BUCHANS GROUP
LAKE
INDIAN
SKIDDER BASALT
RED
TULKS HILL VOLCANICS
HARMSWORTH STEADY
CONGLOMERATE
LONG LAKE
ROGERSON
Noel
Paul's Brook
Lake Douglas
N
0
10
20
Kilometres
KEY
VICTORIA LAKE GROUP
Tulks Hill volcanics
Upper basalt
Tulks Hill/Harmsworths Steady
Victoria Mine sequence
Tally Pond volcanics
Lake Ambrose basalts
'Sedimentary facies'
Valley Brook basalts
Tom Joe Brook basalts
ADJOINING SEQUENCES
Lemotte's Ridge
Harbour Round basalts
Diversion Lake group
Carter Lake
Lake Douglas
Pine Falls Formation

Figure 3. *Distribution of major mafic flow units within and adjoining the Victoria Lake Group.*

field on the discriminant diagram of Garcia (1978). These rocks probably formed as 'island-arc tholeiites'; (b) other mafic flow units within the Tulks Hill volcanics fall within either the 'ocean-floor basalt' or 'calc-alkaline' fields of Garcia (1978). For example, the mafic unit (Upper basalt) overlying the major felsic pyroclastic unit consists of Ti-rich basalts and plot within the 'ocean-floor basalt' field of Garcia (1978). They are tentatively interpreted to represent 'within-plate' volcanism. Mafic flows at the north end of the Tulks Hill volcanics near Victoria Mine, at Victoria River bridge and Valley Brook, plot in the calc-alkaline field; (c) rocks surrounding and/or in contact with the Victoria Lake Group south of Red Indian Lake, all plot in the 'ocean-floor basalt' field. Rocks from the Pine Falls Formation and Lemotte's Ridge basalt appear to be transitional between the 'island-arc tholeiite'–'ocean floor basalt' field and the 'ocean-floor basalt' field. Rocks within the 'ocean-floor basalt' field with high TiO_2 values appear to be represented by rocks of the Harbour Round basalts, Carter Lake volcanics, Upper basalt of the Tulks Hill volcanics and the Diversion Lake group and probably represent 'within plate' basalts.

2) Geochronological and paleontological studies indicate that at least two generations of volcanic sequences are present within the Victoria Lake Group. The Tally Pond volcanics give a late Cambrian U–Pb zircon age of approximately 517 Ma (Dunning, 1986). Felsic volcanic rocks in the southernmost part of the Tulks Hill volcanics have yielded a similarly old U–Pb zircon age (G.R. Dunning, personal communication, 1987). A single conodont, collected from a limestone locality near the Jacks Pond prospect within the Tulks Hill volcanics, was identified as Tremadoc in age (C.R. Barnes, personal communication, 1987). This indicates that the Tulks Hill and Tally Pond volcanics are of similar age. However, the rocks at the mouth of Victoria River, interpreted to be at the north end of the Tulks Hill volcanics, give a U–Pb zircon age of $462\ ^{+4}_{-2}$ (Dunning, *et al.*, 1987), which is in agreement with a conodont age of Llanvirn–Llandeilo (Kean and Jayasinghe, 1980, 1982). This suggests a stratigraphic and/or structural break within the Tulks Hill volcanics. This is also supported by the lead-isotope data, which indicate that lead from the Victoria Mine is more radiogenic than lead from deposits in the southern part of the Tulks Hill volcanics (Swinden and Thorpe, 1984), and by the geochemical data presented above. Geochronological and paleontological studies of the Tulks Hill volcanics are still in progress.

3) Infrared imagery and gradiometer data (Geological Survey of Canada, 1985a,b,c,d,e) show a number of northeast and north-northeast-trending linears and anomalies (Figure 4). These can be interpreted as faults, in particular thrust and strike-slip faults, and indicate that faulting may be an important element of the geological history of this area. A number of north-northeast-trending gradiometer anomalies are coincident with physiographic linears and may represent significant structural breaks, e.g., the north-northeast-trending linear anomaly coincident with Rogerson Lake. There is also a number of cross-structures that could be faulting or fracturing related to late regional flexuring.

4) Many of the mineral showings occur along or close to the interpreted structures (Figure 4), raising the possibility that these structures acted as conduits for fluids. Some of the northeast-trending structures may be developed on earlier, older structures that controlled loci of volcanism and massive sulphide deposition (Kean and Evans, 1986). Epithermal-like alteration systems appear to be restricted to the northeast-trending structures within the major felsic pyroclastic units of the Tulks Hill volcanics. However, shear-related gold mineralization appears less restricted and occurs along structures of various orientation.

5) The volcanogenic massive sulphide deposits and showings are the same age as the enclosing felsic volcanic rocks. Hence, there are at least two ages of volcanogenic mineralization within the Victoria Lake group, because the mineralization occurs both in the Upper Cambrian–Lower Ordovician 'island-arc tholeiite' sequences (e.g., Tulks Hill, Tulks East, Jacks Pond and Duck Pond) and the Llanvirn–Llandeillo 'calc-alkaline' sequences (e.g., Victoria Mine). The 'within-plate' 'ocean-floor basalt' sequences contain no known mineralization.

The gold mineralization occurs in a variety of rock types and may be of widely varying ages. For example, gold occurs associated with epithermal-style alteration in Cambro-Ordovician rocks and in quartz veins in shear zones developed along Silurian(?) and Devonian nonconformities. However, as all types of gold mineralization are associated with shear zones and auriferous quartz veins that are both deformed by and postdate the shearing, the age of mineralization is not well defined. The shear-zone model may at least represent an important remobilization factor for the mineralization associated with the epithermal-style alteration (e.g., Midas Pond, Bobbys Pond). Shearing is probably the major controlling factor for the mineralization associated with faults developed along stratigraphic and/or lithological breaks and other structural linears. This mineralization occurs in a number of different lithologies of different ages, including granite, conglomerate and chloritoid-bearing felsic volcanics of the Tally Pond volcanics (e.g., Spencers Pond area).

$^{40}Ar/^{39}Ar$ age dating of sericite from three massive sulphide deposits and one gold showing all give similar Early Devonian ages (Figure 5, Table 1). These ages probably reflect overprinting (resetting) by the Acadian deformation.

6) Newly mapped exposures of conglomerate similar to the Rogerson Lake Conglomerate occur to the south and east of the Crippleback Lake Quartz Monzonite of Kean and Jayasinghe (1982). Similar outcrops also occur east of Diversion Lake to the northeast. The conglomerate is interpreted to swing eastwards in the Sandy Lake area; however, it also appears to continue to the northeast following the trend of the Victoria Lake Group. This suggests that the conglomerate may also nonconformably overlie the Crippleback Lake Quartz Monzonite (a similar situation to the Valentine Lake area–see appendix, #20). Extensive alteration is also present in felsic volcanic rocks that underlie the conglomerate.

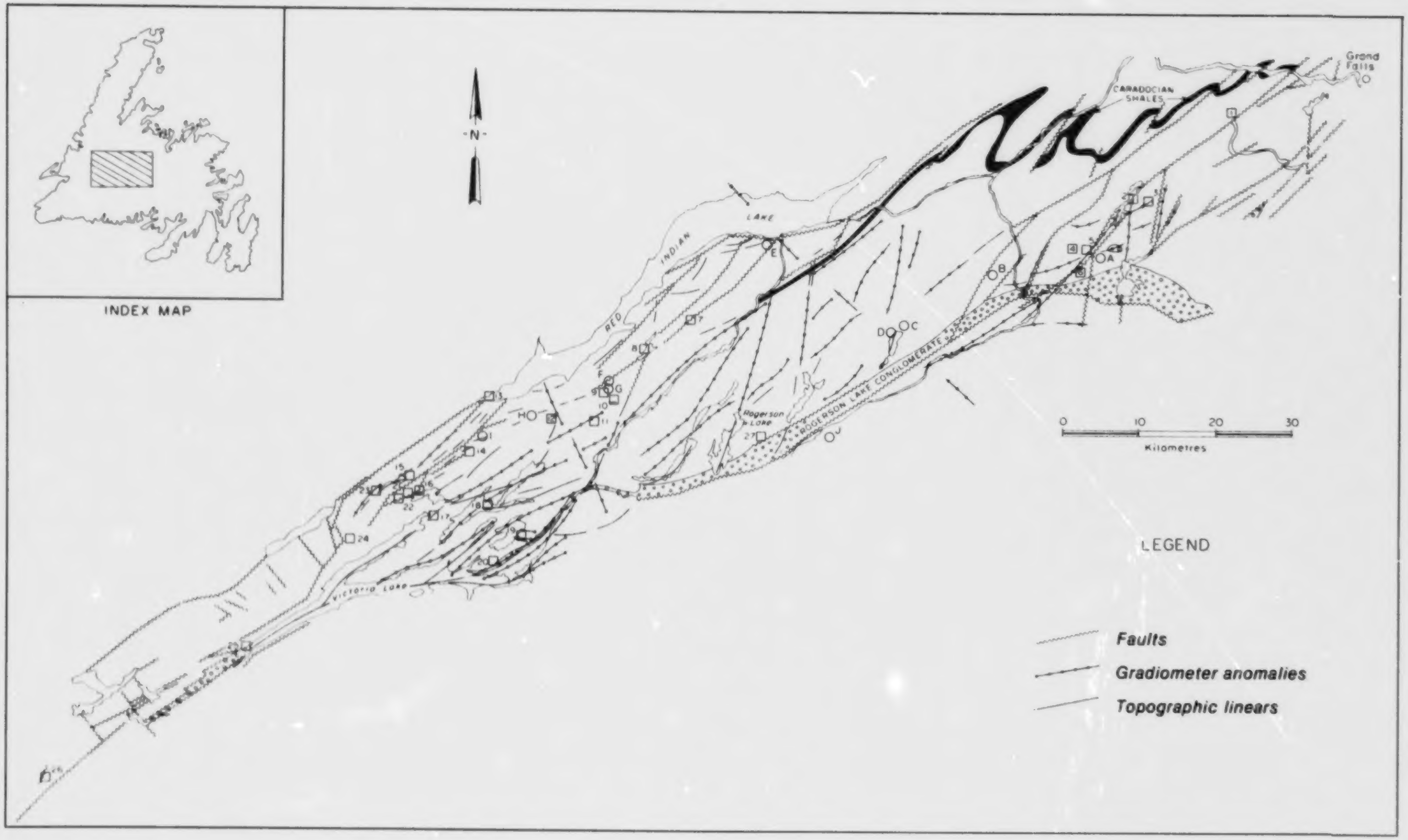

INDEX MAP
N
Grand Falls
CARADOCIAN SHALES
RED INDIAN LAKE
Rogerson Lake
ROGERSON LAKE CONGLOMERATE
Victoria Lake
A
B
C
D
E
F
G
H
I
J
1
3
7
8
9
10
11
13
14
15
16
17
18
19
20
21
22
23
24
25
0
10
20
30
Kilometres
LEGEND
Faults
Gradiometer anomalies
Topographic linears

Figure 4. *Distribution of major structural linears and geophysical anomalies in the area showing the distribution of significant mineralization–alteration. O–volcanogenic sulphides; □–epigenetic alteration and gold mineralization. Letters and numbers keyed to the appendix.*

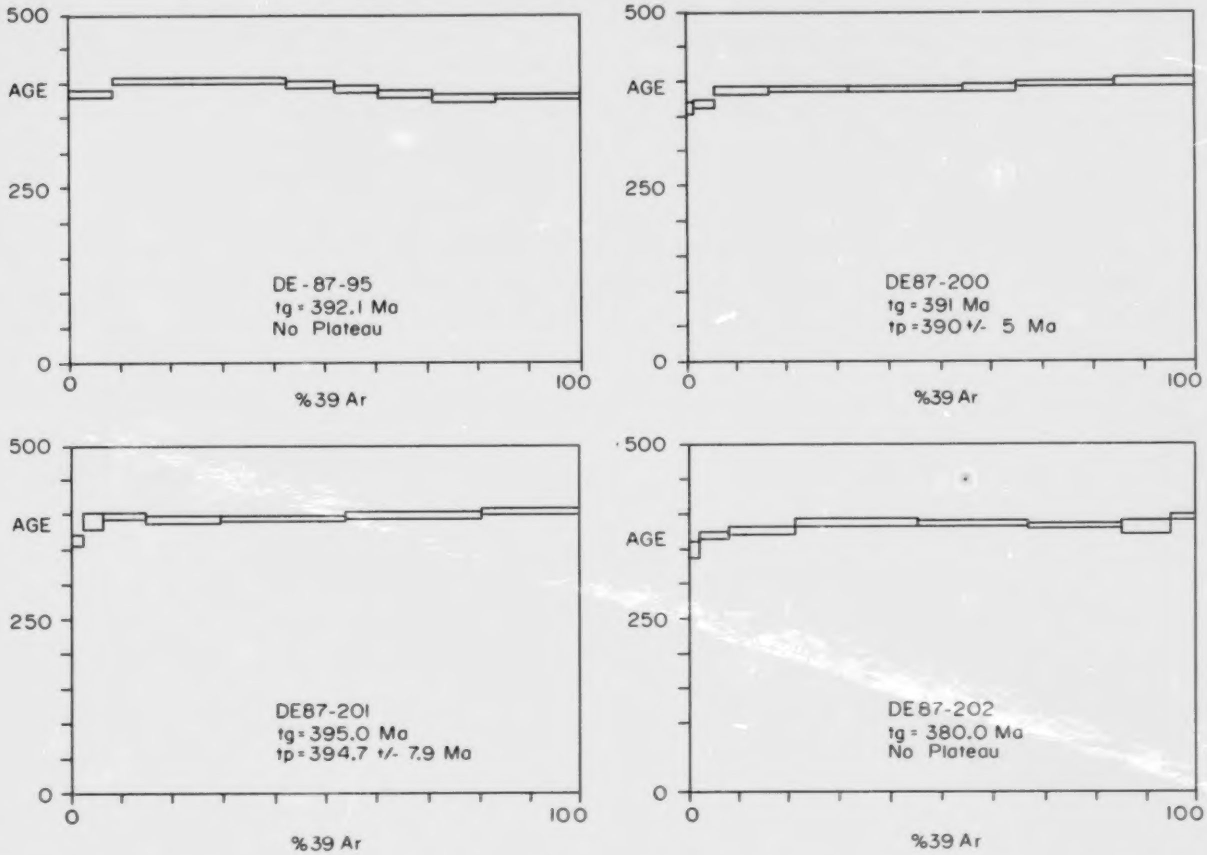


Figure 5. *$^{40}Ar/^{39}Ar$ incremental-release spectra of sericites from Bobby's Pond (DE-87-95); Tulks Hill (DE-87-200); Jacks Pond (DE-87-201); and Duck Pond (DE-87-202).*

Table 1. ^{40}Ar/^{39}Ar ages of sericite obtained from massive sulphide and epigenetic gold deposits.

Sample Number	Location	Sample Description	Association	^{40}Ar/^{39}Ar Age
DE-87-95	Bobbys Pond	Sericite	Epithermal alteration	392 ± 4
DE-87-200	Tulks Hill	Sericite	Massive sulphide	391 ± 4
DE-87-201	Jacks Pond	Sericite	Massive sulphide	395 ± 8
DE-87-202	Duck Pond	Sericite	Massive sulphide	380 ± 5

SUMMARY

The Victoria Lake Group consists of a Upper Cambrian–Lower Ordovician sequence of 'island-arc tholeiites' and more Ti-rich, 'within plate' basalts and a Llanvirn–Llandeillo sequence of 'calc-alkaline' basalt and andesite. The mafic volcanic rocks adjoining the Victoria Lake Group on the south side of Red Indian Lake appear to be mostly formed in a 'within-plate', ocean-floor paleotectonic setting. The identification of linears interpreted to be faults and thrusts, and often associated with major lithological and/or stratigraphic contacts, may be crucial in reconstructing the stratigraphy, structure, paleotectonic environment and identifying potential sites of mineralization.

The volcanogenic sulphide mineralization, hosted by felsic volcanic rocks, appears to be restricted to 'island-arc tholeiitic' and 'calc-alkaline' volcanic rocks. The Ti-rich sequences contain no known significant mineralization. The gold mineralization occurs in a variety of rock types and probably represents mineralizing systems ranging in age from Cambro-Ordovician to Siluro-Devonian. A common feature to all the gold mineralization is their presence within shear zones.

ACKNOWLEDGMENTS

We kindly thank our many colleagues, in particular J. Tuach, G. Dunning and S. Swinden, for their interest, data and many discussions on central Newfoundland geology, particularly the Victoria Lake Group. BP-Selco and Noranda are thanked for providing information on showings and prospects. The manuscript has benefited from critical readings by John Tuach and Scott Swinden.

REFERENCES

Dunning, G.R.

1986: Precise U–Pb zircon geochronology applied to Newfoundland ophiolites, granitoid and felsic volcanic rocks. Program with Abstracts, Newfoundland Section, Geological Association of Canada, Annual Spring Meeting, pages 11-12.

Dunning, G.R., Kean, B.F., Thurlow, J.G. and Swinden, H.S.

1987: Geochronology of the Buchans, Roberts Arm and Victoria Lake Groups and Mansfield Cove Complex, Newfoundland. Canadian Journal of Earth Sciences, Volume 24, pages 1175-1184.

Evans, D.T.W. and Kean, B.F.

1986: Geology of the Jacks Pond volcanogenic sulphide prospects, Victoria Lake Group, central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 59-64.

1987: Gold and massive sulphide mineralization in the Tulks Hill volcanics, Victoria Lake Group, Central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 103-111.

Garcia, M.O.

1978: Criteria for the identification of ancient island arcs. Earth Science Reviews, Volume 14, pages 147-165.

Geological Survey of Canada

1985a: Aeromagnetic vertical gradient map, Badger, Newfoundland, 1:50,000 scale. Geophysical Series, Map C40096G.

1985b: Aeromagnetic vertical gradient map, Star Lake, Newfoundland, 1:50,000 scale. Geophysical Series, Map C41137G.

1985c: Aeromagnetic vertical gradient map, Lake Ambrose, Newfoundland, 1:50,000 scale. Geophysical Series, Map C41138G.

1985d: Aeromagnetic vertical gradient map, Noel Paul's Brook, Newfoundland, 1:50,000 scale. Geophysical Series, Map C41139G.

1985e: Aeromagnetic vertical gradient map, Victoria Lake, Newfoundland, 1:50,000 scale. Geophysical Series, Map C41140G.

Kean, B.F.

1977: Geology of the Victoria Lake map area (12A/6), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-4, 11 pages.

1985: Metallogeny of the Tally Pond volcanics, Victoria Lake Group, central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 89-93.

Kean, B.F. and Evans, D.T.W.

1986: Metallogeny of the Tulks Hill volcanics, Victoria Lake Group, central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 51-57.

Kean, B.F. and Jayasinghe, N.R.

1980: Geology of the Lake Ambrose (12A/10)–Noel Paul's Brook (12A/9) map area, central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-2, 29 pages.

1982: Geology of the Badger map area (12A/16), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 81-2, 37 pages.

Pickett, J.W.

1987: Geology and geochemistry of the Skidder Basalt. *In* Buchans Geology Newfoundland. *Edited by* R.V. Kirkham, Geological Survey of Canada, Paper 86-24, pages 195-218.

Swinden, H.S. and Thorpe, R.I.

1984: Variation in style of volcanism and massive sulphide deposition in early to middle Ordovician Island-Arc sequences of the Newfoundland Central Mobile Belt. Economic Geology, Volume 79, pages 1596-1619.

Thurlow, J.G.

1981: Geology, ore deposits and applied rock geochemistry of the Buchans Group, Newfoundland. Memorial University of Newfoundland, Ph.D. thesis, 305 pages.

Tuach, J.

1987: List of gold occurrences and deposits in Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Divison, Open File 1510, 36 pages.

Williams, H.

1979: Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, Volume 16, pages 792-807.

APPENDIX

Mineralization in the Victoria Lake Group

(Data Sources: Tuach, 1987; BP-Selco; Noranda; Kean, 1985; Kean and Evans; 1986; Evans and Kean, 1986, 1987). Keyed to Figure 4.

Epigenetic alteration and gold mineralization:

1. *Lynx Pond:* Fine grained, massive pyrite veins in greywacke (Au–155 ppb).

2. *Evans showing:* Carbonatized, chloritized, sericitized, and pyritized sheared quartz monzonite with pyrite stringer and quartz–carbonate veins carrying pyrite and galena.

3. *Coronation Lake:* Disseminations and veins of pyrite, molybdenite and chalcopyrite in silicified zones in the mafic phase of the Crippleback Lake Quartz Monzonite (Au–60 ppb).

4. *Island Pond:* Possible stockwork alteration developed in Crippleback Lake Quartz Monzonite. It consists of sericite, carbonate and pyrite and hydrothermal breccias containing minor disseminated and stringer chalcopyrite and traces of molybdenite (Au–90 ppb).

5. *Jims Hill:* Disseminated and stringer pyrite, minor chalcopyrite and galena in carbonate-altered Crippleback Lake Quartz Monzonite.

6. *Shoulder Blade Lake:* Disseminated pyrite and coarse grained euhedral arsenopyrite. Developed in strongly hematized and silicified felsic volcanics containing quartz–carbonate veins (Au–245 ppb in arsenopyrite bearing felsic volcanics).

7. *Bobbys Pond and North Pond:* Altered felsic volcanic rocks of the Tulks Hill volcanics characterized by sericite, pyrophyllite, alunite, native sulphur and orpiment. Semimassive pyrite with pyrophyllite and sericite–silica alteration developed in similar rocks approximately 2.5 km to northeast at North Pond. The alteration zone is surrounded by sericite schist and appears to be preserved as large boudins. It probably represents an epithemal alteration system (Au–156 ppb in sericite schist envelope).

8. *Harbour Round:* Disseminated and stringer pyrite in Tulks Hill volcanics. No further information available.

9. *Jacks Pond West:* Quartz-carbonate veins containing coarse grained pyrite and minor galena in sericitized felsic volcanic rocks of the Tulks Hill volcanics (Au–70 ppb).

10. *Side of the Hill:* Disseminated and stringer pyrite, chalcopyrite, galena and sphalerite in sericitized felsic volcanics of the Tulks Hill volcanics (Au–20 ppb, Ag–10.7 ppm, Zn–4,500 ppm, Pb–6,600 ppm, Cu–465 ppm, Hg–1700 ppb; and Cd–11.5 ppm.)

11. *Roebucks Pond:* Altered Tulks Hill volcanics. No further information available.

12. *Costigan Brook:* Altered Tulks Hill volcanics. No further information available.

13. *Star Brook:* Sheared and altered volcanic rocks with quartz veins (Au–0.12 oz/t, Ag–0.7 oz/t).

14. *Tulks Extension:* Boulders with auriferous quartz veins.

15. *West Tulks:* Silicified, banded and possibly mylonitized cherty-type rocks of the Tulks Hill volcanics containing galena and Au-bearing quartz veins. Probably in part silicified volcanic rocks and/or silica precipitate.

16. *Midas Pond:* Pyrite, carbonate, feldspar, tourmaline, paragonite and gold-bearing quartz veins hosted by sericitized, silicified, pyrophyllitized and kaolinitized, quartz-eye felsic volcanics of the Tulks Hill volcanics. The pyrophyllitized rock contains thin fluorite veinlets and forms the structural hanging wall to the sericitized and silicified, quartz-veined mineralized zone. A banded mafic unit (tuff?) exhibiting strong carbonate and pyrite alteration is in gradational contact with and forms the structural footwall to the mineralized zone. The alteration system is developed within an anastomising northeast-trending shear zone (Au–7300 ppb).

17. *Victoria Lake NW:* Disseminated pyrite in altered felsic volcanic rocks of the Tulks Hill volcanics. No assays available.

18. *Long Lake:* Pyrite and gold-bearing quartz veins associated with a granite emplaced into a shear zone developed in volcanic rocks of the Tulks Hill volcanics. No assays available.

19. *Frozen Ear Pond:* Quartz vein in altered Valentine Lake Quartz Monzonite. No further information available.

20. *Valentine Lake:* Gold-bearing, pyrite–tourmaline–andradite quartz–feldspar veins in the sheared margin of the Valentine Lake Quartz Monzonite. Scheelite and tungstenite are also present. Similar quartz veins also cut the overlying conglomerate. Mineralization may be related to a shear zone developed parallel to the nonconformity between the monzonite and the Silurian(?) Rogerson Lake Conglomerate.

21. *Road (Camp) showing:* Galena, sphalerite and pyrite-bearing quartz veins in sericitized and carbonate-rich felsic volcanics of the Tulks Hill volcanics (Au–5500 ppb).

22. *Glitter Pond:* Massive barite lens or vein with local anomalous gold values.

23. *Stag Pond:* Auriferous arsenopyrite-bearing quartz boulders.

24. *Pats Pond:* Boulders containing quartz veins with pyrite, sphalerite, galena, scheelite, stibnite and significant gold values. (Float: Au–0.60 oz/t, Ag–36.7 oz/t, Cu–0.08%, Pb–7.5%, Zn–1.1%, WO_3–2.9%, Bi–0.3%; Drill Hole (4.9 ft.): Au–0.01 oz/t, Ag–3.2 oz/t, Cu–.05%, Pb–0.78%, Zn–1.1%.)

25. *Victoria Lake South:* Pyritized and sheared gabbroic rocks within the Victoria Lake Group (Au–900 ppb).

26. *Second Exploits:* Gold, galena, sphalerite and specular hematite in quartz float and 1- to 2-cm-wide quartz–carbonate veins cutting altered granite. Stratigraphically beneath the nonconformably overlying Devonian Windsor Point Group. Developed within a splay of the Cape Ray fault system. *(In situ* veins: Au–7.5 g/t, Ag–8 g/t. Float: visible gold (Au–25 g/t)).

27. *Spencers Pond:* Sericitic felsic volcanics and synvolcanic intrusives of the Tally Pond volcanics. Anomalous gold values associated with chloritoid-bearing volcanics; local pyrophyllite development.

Volcanogenic sulphides

A. *Old Sandy Road:* Massive to banded pyrite and trace chalcopyrite in mafic volcanics of the Tally Pond volcanics.

B. *Burnt Pond:* Thin lens of zinc, copper and minor lead in felsic volcanic rocks of the Tally Pond volcanics. Associated sericite and chlorite alteration.

C. *Boundary:* Volcanogenic massive sulphide containing zinc, copper, minor lead, and silver. Occurs in felsic pyroclastic rocks of the Tally Pond volcanics. Breccia ore and well-bedded, laminated massive sulphides present with associated sericite–chlorite pyrite–chalcopyrite stockwork (0.5 million tonnes at 4% Zn, 3.5% Cu, 1% Pb and 34 g/t Ag, (Au)).

D. *Duck Pond:* Zinc, copper and minor lead (Au, Ag) volcanogenic massive sulphide in felsic volcanic rocks of the Tally Pond volcanics. Banded, massive (unbanded) and brecciated sulphides are present and there is an associated sericite, chlorite, pyrite–chalcopyrite stockwork (As of Nov., 1987: 3.6 million tonnes at 7.58% Zn, 3.71% Cu, 1.36% Pb, 72.34 g/t Ag, and 1.2 g/t Au).

E. *Victoria Mine:* Copper, zinc and lead volcanogenic sulphides in altered felsic pyroclastic rocks of the Tulks Hill volcanics. The mineralization occurs both as stratiform massive sulphides and as stockwork stringers and disseminations. Lead mineralization is mainly associated with the dolomitic cap to the massive sulphides. Hydrothermal alteration consisting of sericite, chlorite, pyrite and chalcopyrite accompanies the mineralization. (Grab samples from the dumps: 7.5% Cu, 2.4% Zn, 1.5% Pb, 140 ppb Au and 12 ppm Ag.)

F. *Cathy's Pond:* Massive pyrite with trace base metals hosted by felsic volcanics of the Tulks Hill volcanics (Au–165 ppb).

G. *Jacks Pond:* Pyritic, minor chalcopyrite, volcanogenic sulphide deposit in felsic volcanics of the Tulks Hill volcanics. Appears to be mainly stockwork mineralization with associated sericite, silica and chlorite alteration (4 lenses up to 1.0 million tonnes with sporadic Cu, Pb and Zn values).

H. *Tulks East:* Pyritic volcanogenic massive sulphide in felsic volcanic rocks of the Tulks Hill volcanics. It consists of three stratifrom massive sulphide lenses (A, B and C) containing 5.6 million tonnes of pyritic massive sulphides with low base-metal values. Sericite, silica, chlorite and pyrite–chalcopyrite stockwork associated with the stratiform sulphides: A) 4.5 + million tonnes: 1.5 % Zn, 0.24% Cu, 0.12% Pb, 8.5 g/t Ag, trace Au; B) 0.2 million tonnes: 8.7% Zn, 0.66% Cu, 1.26% Pb, 58.7 g/t Ag, 0.14 g/t Au and C) 0.9 million tonnes: Less than 1% combined base metals).

I. *Tulks Hill:* Zinc, copper and minor lead volcanogenic massive sulphides in felsic pyroclastic rocks of the Tulks Hill volcanics. Four stratiform lenses with a total tonnage of approximately 0.75 million tonnes underlain by sericite, silica, chlorite and pyrite–chalcopyrite stockwork alteration. (0.75 million tonnes 5-6% Zn, 2% Pb, 1.3% Cu, 0.4 g/t Au and 41 g/t Ag).

J. *Havens Steady:* Zinc–copper and minor lead volcanogenic sulphide mineralization in felsic volcanic rocks. Stringer and disseminated sulphides in sericitic alteration characterizes this prospect.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 331-341

QUATERNARY MAPPING AND DRIFT EXPLORATION IN THE CENTRAL MINERAL BELT (13K/7 AND 13K/10), LABRADOR

Martin Batterson, Angus Simpson[1] and Sharon Scott[2]
Quaternary Geology Section

ABSTRACT

Quaternary mapping in the Central Mineral Belt (13K/7 and 13K/10) is a continuation of work started in 1986 in the Melody Lake area (13K/9 and 13J/12). During the 1987 program, two major flow directions were identified. There was an ubiquitous northeast-directed flow across the area that is consistent with the northeastward flow identified to the east. However, in the Moran Lake area, an eastward-directed flow is the most recent, although it has a limited easterly extent, both altitudinally and laterally. In the Kanairiktok Valley, sediments related to the eastward flow event overly marine silts and clays. This flow may have re-entered the Kaipokok Valley in the West Micmac Lake area.

Upland areas are bedrock dominated. Tills in the map area are generally thin and discontinuous, except near Nipishish Lake. Outwash sediments fill the major valleys, and deltas related to small proglacial lakes are also evident. Fossiliferous marine sediments occur in the Kaipokok and Kanairiktok valleys, although in the latter valley they are overlain by ice-contact outwash sediments. A major glaciomarine delta east of Moran Lake has well-defined levels at 105 m and about 130 m above sea level.

The use of indicator lithologies has demonstrated that dispersal of clasts reflect the most recent glacial-flow events. Dispersal trains are oriented eastward in the western part of the study area, but are deflected northeastward in the Moran Lake area. The previous impression of single glacial-flow pattern in this part of Labrador has been negated. Detailed drift-exploration programs should be placed within a regional framework.

INTRODUCTION

This study represents the fourth year of a five-year project on the Quaternary geology of selected parts of Labrador. The study is part of a joint Provincial–Federal effort to better define and describe Quaternary events in Labrador, particularly in the Central Mineral Belt. The overall aim is to provide a framework in which mineral exploration can become better focused in areas of heavy drift cover. Previous studies have been site specific: dispersal from the Strange Lake Alkalic Complex (Batterson *et al.*, 1985), and boulder tracing in the Two-Tom Lake area (Batterson and LeGrow, 1986).

The present study continues a project that commenced in 1986 to examine the Quaternary geology and its potential effects on mineral-exploration programs in the eastern part of the Central Mineral Belt. Work in 1986 focused on the Melody Lake area (Batterson *et al.*, 1987), an area of intense mineral exploration in the 1950's and 1960's. In 1987, the field area was farther west. Again, the emphasis is on the surficial environment (glacigenic sediment types, ice-flow indicators, glacial transport distance and direction, terrain description) as a key to understanding the subsurface environment and, in particular, to the delineation of areas of mineral potential.

Location and Access

The Moran Lake study area encompasses NTS map sheets 13K/7 and 13K/10, a total area of approximately 1850 km^2 between 60°30′ and 61°00′ west longitude and 54°15′ and 54°45′ north latitude (Figure 1). Base camp was on a spit on the south side at the western end of Moran Lake, approximately 140 km north of Goose Bay. The nearest community was Postville, roughly 95 km to the northeast on Kaipokok Bay. Access to the field area is by helicopter or float plane, although the study area itself may be traversed by canoe or by foot.

Physiography

The study area is within the 'Postville ecological land region' (Lopoukhine *et al.*, 1977). Physiography is diverse, ranging from level bog and marine sediment-covered

---

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

[1] Department of Earth Sciences, Memorial University, St. John's, Newfoundland A1B 3X5

[2] Department of Geography, Memorial University, St. John's, Newfoundland A1B 3X9

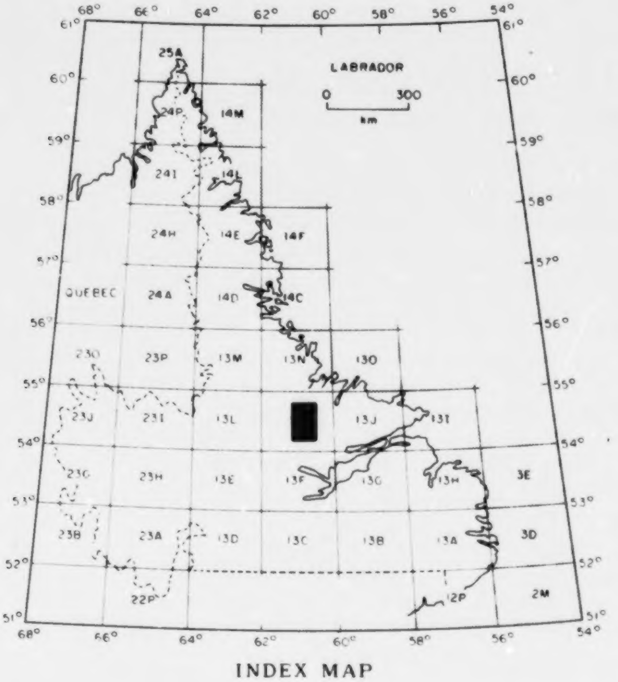


Figure 1. *Location of field area.*

lowlands in the lower reaches of the Kaipokok Valley, to the outwash-filled Kanairiktok Valley, to the rugged, bedrock-dominated uplands north and south of the Kaipokok and Kanairiktok valleys.

Vegetation is also diversified, a reflection of parent material. Well-drained glaciofluvial sands and thin tills support only spruce–lichen associations. Forest growth is sparse, and is best developed along river valleys, such as the Kaipokok Valley, or along lower slopes. The modern pollen spectra reflects the Boreal Woodland vegetational zone of this part of Labrador (Macpherson, 1981).

The area has an interior Labrador climatic regime (Banfield, 1981). Winters are long and severe, with heavy snow accumulation and extended periods below -15°C. Summers are short and cool, although daily maxima may be high (mid 20's C). Annual precipitation is 900 to 1100 mm with a summer maximum. The area lies within the zone of discontinuous permafrost (French, 1976).

Previous Quaternary Geology Research

Despite the long history of exploration in the area, knowledge of the Quaternary geology remains scant, and is restricted to several broad overviews. Rogerson (1982), based largely on data generated by the Glacial Map of Canada (Prest *et al.*, 1968), suggested that glacial-dispersal patterns over Labrador were 'relatively simple', and followed the structural grain in the form of the Grenville Front. Ice-flow patterns, then, were expected to have a general arcuate pattern, issuing from the Labrador Trough and flowing out through the major northeastward-oriented coastal inlets. Recent work (Batterson *et al.*, 1987; Thompson and Klassen, 1986; Klassen, 1983, 1984) has begun to redefine ice-flow patterns in the Central Mineral Belt, and has highlighted several regional-flow events that cross the structural grain. Individual flows may also be topographically controlled, adding to the complexity of dispersal patterns.

Surficial mapping at 1:500,000 scale, based largely on aerial photograph analysis with limited ground checking has been completed for much of the Central Mineral Belt (Fulton, 1986). A reapprasial of this data and a refinement of the surficial map is a component of this current project.

Geological Setting

The study area lies mostly in the Central Mineral Belt, an east-trending belt of Proterozoic supracrustal sedimentary and volcanic rocks and associated granites (Greene, 1974). To the north these rocks unconformably overlie Archean gneisses of the Nain Structural Province, or reworked Archean rocks that comprise the Makkovik Province. To the south, granites of Elsonian age display a strong Grenvillian fabric. The study area has been mapped in detail by Ryan (1984) (Figure 2); the following summary of the geology of the area comes largely from Ryan's report.

Archean Rocks

The northwestern part of the study area comprises Archean rocks of the Nain Province. These rocks, part of the Kanairiktok Valley complex, consist of quartzofeldspathic gneisses (Maggo gneiss), schistose metavolcanics (Florence Lake group) and granitoid rocks (Kanairiktok Intrusive Suite). To the east, rocks of similar lithology exist. However, many have undergone partial retrogression during the Hudsonian Orogeny, from the amphibolite facies of the Kanairiktok Valley complex to a greenschist facies that dominates rocks of the Kaipokok Valley complex.

There is little known mineralization associated with Archean rocks in the study area except in the Florence Lake group, which has asbestos and uranium showings and potential for platinum-group elements (Wardle, 1987).

Aphebian Rocks

These rocks overly the Archean rocks, and occupy northeast-trending belts in west-central and northern parts of the study area. In the west, they comprise the Moran Lake Group (Unit 3), a sequence of quartzite, slate, dolostone and greywacke (Warren Creek Formation), overlain by both massive and pillowed, mafic volcanic rocks (Joe Pond Formation). Polydeformed metasedimentary and metavolcanic (Unit 4) equivalents of the Moran Lake Group occur to the east in the Kaipokok Valley.

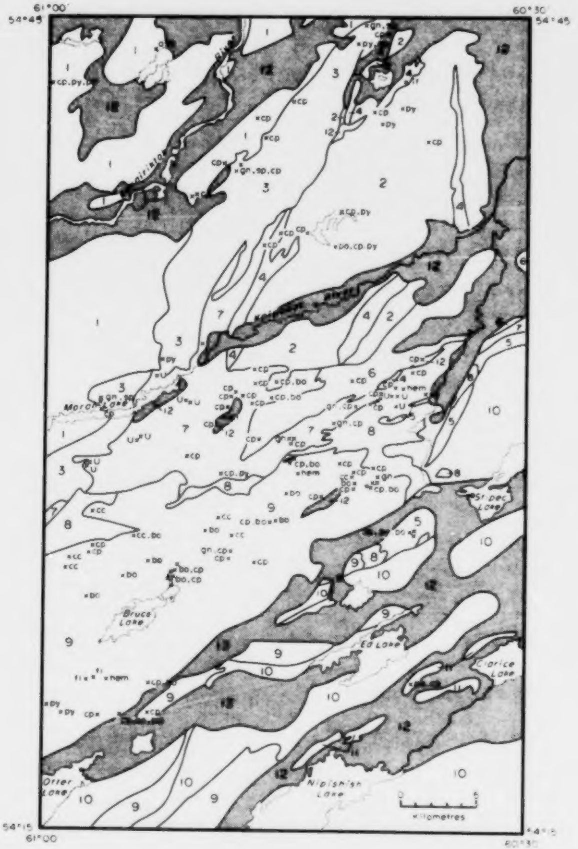


Figure 2. *Geological setting and location of mineral occurrences.*

LEGEND (Figure 2)

PLEISTOCENE

12 *Drift*

PROTEROZOIC

Paleohelikian

11 Michael Gabbro

10 Nipishish Lake intrusive suite: *granite, granodiorite*

Bruce River Group (Units 7–9)

9 Sylvia Lake Formation: *volcanosedimentaries and volcaniclastics*

8 Brown Lake Formation: *volcaniclastic sandstones*

7 Heggart Lake Formation: *sandstones and conglomerates*

6 Southern Kaipokok Valley intrusive suite: *granite, granodiorite*

Aphebian

5 *Metavolcanic and metasedimentary rocks*

4 *Polydeformed rocks equivalent to Moran Lake Group*

3 Moran Lake Group: *sandstone, dolostone, tuffs*

ARCHEAN

2 Kaipokok Valley Complex: *polydeformed equivalents of Kanairiktok Valley Complex*

1 Kanairiktok Valley Complex: *granite, granodiorite, tuffs, gneisses*

Mineral Occurrence Abbreviations

asb	*asbestos*
bo	*bornite*
cc	*chalcocite*
cp	*chalcopyrite*
fl	*fluorite*
gn	*galena*
hem	*hematite*
i-f	*iron formation*
po	*pyrrhotite*
py	*pyrite*
sp	*sphalerite*
U	*uranium*

In the Stipec Lake area, there are metavolcanic and metasedimentary rocks (Unit 5), which are probable remnants of Aphebian strata. These rocks are similar to Moran Lake Group equivalents in the Kaipokok Valley.

Rocks of the Moran Lake Group contain base metal, precious metal and uranium showings, many of which are the result of exploration during the 1950's, particularly by the American Metals Company (AMCO) and British Newfoundland Exploration (BRINEX). Of importance are the Green Pond showing, which contains up to 17.87 percent zinc and 25 g/t silver (Moore, 1954) and uranium showings near Moran Lake.

Paleohelikian Rocks

Four major Paleohelikian rock units occur in the study area. Pink granite and hornblende granodiorite (Junior Lake Granodiorite) of the Southern Kaipokok Valley intrusive suite (Unit 6) occur in the central part of the area. These rocks are unconformably overlain by sedimentary and volcanic rocks of the Bruce River Group, including sandstones and polymictic conglomerate (Heggart Lake Formation, Unit 7), volcaniclastic sandstones (Brown Lake Formation, Unit 8) and volcanic and volcaniclastic rocks (Sylvia Lake Formation; Unit 9). The Bruce River Group is itself intruded by the third major group of rocks, namely granitic rocks of the Nipishish Lake intrusive suite (Unit 10), which may be subdivided into a coarse grained granite, granodiorite and monzonite (Otter Lake–Walker Lake granite) and a biotite to muscovite granite (Crooked River granite). The latter only outcrops in the southeastern corner of the map area. The youngest Paleohelikian rocks in the area are gabbros related to northeast-trending dykes known as the Michael Gabbro (Unit 11).

The Paleohelikian rocks in the study area host both base metals and uranium, particularly in the Bruce River Group. Base-metal showings include chalcopyrite, bornite, chalcocite, pyrite, galena and sphalerite (Moore, 1954), but most produced disappointing results. Of more importance are uranium showings, particularly around Moran Lake. Most were discovered during the 1950's by AMCO and BRINEX, and some (especially the 'C zone') were drilled, although assays were insufficient to maintain interest. More recently, personnel from Saarberg Interplan worked in the Moran Heights area along the contact between Bruce River and Moran Lake Group rocks, and encountered some success following a detailed boulder tracing survey.

There is little known mineralization associated with the Southern Kaipokok Valley intrusive suite, the Nipishish Lake intrusive suite or the Michael Gabbro, within the study area.

Methodology

Mapping and sampling was conducted using a roughly 2- by 2-km grid system. The actual location of sites was determined from a reconnaissance air-photograph analysis and the availability of landing sites. At each site, a pit was dug to a depth that penetrated the surface-weathering horizons (commonly 30 to 50 cm) and a sample of unweathered parent material collected. Clasts (16 to 64 mm range) were collected from either test pits or from the surface, and were used in defining glacial-dispersal patterns. Bedrock was examined for the presence of ice-flow direction indicators.

In areas of known mineralization, samples were collected every 100 m, where possible, in order to more clearly define dispersal patterns. In particular, the uranium showing at Moran Heights was extensively sampled, as a follow up to the work of Vanderveer (1986). The Baikie (Ni) showing near Florence Lake, the Brown Lake (galena–sphalerite–chalcopyrite) showing and the Ellingwood (galena–sphalerite) showing north of Moran Lake were also sampled.

QUATERNARY GEOLOGY

Terrain Units

A generalized surficial geology map showing major terrain features is presented in Figure 3. Six subdivisions are made in the study area.

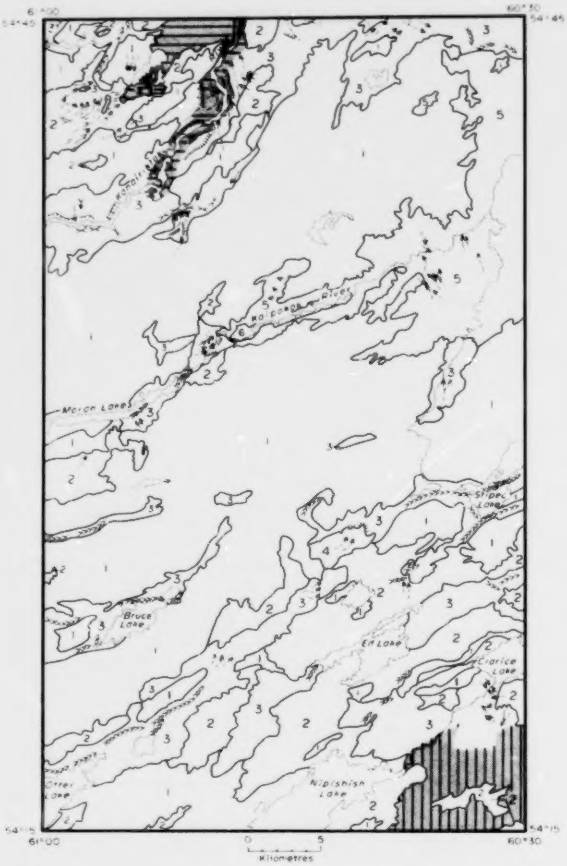


Figure 3. *Generalized surficial geology map.*

Unit 1. Upland areas dominated by bedrock are the most dominant terrain type across the area. Northwest of Moran Lake, these uplands reach 430 m above sea level, whereas south of Moran Lake elevations are generally less than 360 m above sea level. The large area of apparent bedrock domination belies the fact that glacigenic sediment is common, and reaches thicknesses exceeding 2 m, especially in the interfluves between bedrock ridges. However, on bedrock ridges, glacigenic sediment is commonly less than 1 m thick or is absent.

Unit 2. The major area of till across the study area is southeast of the Otter Lake–Stipec Lake valley. Smaller areas are found north of the Kanairiktok Valley and around Moran Lake. The character of the till reflects the underlying geology. Near Nipishish Lake, tills are dominantly sandy, normally consolidated and contain numerous granitic clasts. Tills to the north commonly have a siltier matrix and are reddish in colour, reflecting a significant component of Seal Lake Group lithologies located to the west. The till surface is generally featureless, although erosion channels are locally abundant, especially north of the Kanairiktok River valley.

Legend (Figure 3)

Postglacial

[6] Alluvium: *Fine sand to silt deposited by fluvial action. Occurs as expressionless surface adjacent to modern rivers.*

[5] Marine: *Red, silty to clayey sediment. Commonly capped by fine sand. Commonly rhythmically bedded, especially in the Kanairiktok Valley. May be overlain by glaciofluvial sediments and has no surface expression. Commonly gullied, especially in the Kaipokok Valley. Unstable. Surface cover of organic deposits is common.*

Glacial

[4] Glaciofluvial: *Generally fine- to medium-stratified sands and associated gravels. Moderately to well sorted. Generally confined to valleys. Low relief (less than 3 m); gravel-rich esker ridges (3 to 12 m high) are common.*

[3] Glaciolacustrine or Glaciomarine: *Deltaic deposits comprised of fine- to medium-grained sands and associated gravels. Generally confined to valleys. Flat surfaced. No internal structure noted.*

[2] Till: *Fine sand to silt matrix, 10-30% clast content. Generally massive. Diamicton probably of basal glacial origin. Ubiquitous across area. Not confined to any geomorphic unit. Surface may have hummocks, gullied or featureless expression. Commonly greater than 2 m thick.*

Preglacial

[1] Rock: *Area dominated by bedrock. Numerous pockets of glacigenic sediment present, usually less than 2 metres thick.*

SYMBOLS

⇗ ↗ *Esker (direction known, direction unknown)*

- - -➔ *Meltwater channel*

~ *Moraine, transverse to flow*

⊥⊥⊥ *Fluvial terrace*

☰ *Area underlain by sediment of marine origin*

▥ *Area underlain by till*

Unit 3. Glaciofluvial sediments are common within most of the major valleys that traverse the study area. In the Kanairiktok Valley, individual sections expose greater than 20 m of outwash sand and gravel, and low-lying, lichen-covered plains are underlain by coarse gravels and sands. Crossbedded fine sands are rare and reflect the generally high-energy environment within the valley system. The Otter Lake–Stipec Lake valley also reveal evidence of high-energy flow, but these are dispersed amongst units that reflect calmer, more steady-state flows. Paleoflow directions are generally consistent with present drainage patterns. Gravel-rich eskers are common in both the Kanairiktok and Otter Lake–Stipec Lake valleys, some reaching up to 15 m in height. Glaciofluvial sediment within the Nipishish Lake–Clarice Lake valley is anomalous in that the margin of Nipishish Lake (the down valley end) has only till, whereas the rest of the valley is outwash filled. Outwash grades into till along many of the valley sides, and a distinct boundary is commonly difficult to define. Outwash sediment commonly forms a thin (less than 1 m) veneer over till, especially in the Nipishish Lake area.

Unit 4. Deltaic deposits have been identified at various locations across the area. The most evident is downstream of Moran Lake, where a well-defined glaciomarine delta exists. The delta has at least two major levels, one at about 105 m above sea level, and the other at about 130 m above sea level. The delta is underlain by sediment of marine origin. Another large delta exists in the northeast corner of the study area where outwash waters from the Kanairiktok basin entered the headwaters of the Kaipokok Valley. A similar situation occurs along the southern margin of the Kaipokok Valley where waters exiting the Stipec Lake area entered the marine waters of Kaipokok Bay. The elevation of the delta in this area is similar to the upper level of the Moran Lake delta.

Smaller, probably freshwater deltas, are also present in the Otter Lake–Stipec Lake valley, as for instance, where an eroded terraced surface at an elevation of about 240 m above sea level shows evidence for the existence of a shallow proglacial lake, upstream from Stipec Lake.

Unit 5. Three of the prominent or possible deltas outlined above formed as meltwater entered the Kaipokok Valley, which was filled with seawater. Marine sediments fill the Kaipokok Valley, up to an elevation of at least 100 m above present sea level, and have modified sediments probably 20 m above that. Marine sediments also underlie outwash sediments in the Kanairiktok Valley.

The character of marine sediment varies between the Kanairiktok and Kaipokok valleys. In the Kaipokok Valley, sediment is commonly a massive to slightly laminated red clay that grades upward into a fine sand capping, less than 1 m thick. In the Kanairiktok Valley, red-coloured, rhythmically bedded silt and clay dominate, although grey fine sand layers are also present. The red colour is a reflection of their source in the Seal Lake Group mudstones or tills derived from those rocks (Thompson and Klassen, 1986). Individual laminae range from 1 to 15 mm. This pronounced lamination is absent within the Kaipokok Valley. Marine sediment within both the Kaipokok and Kanairiktok valleys are fossiliferous.

Within both valleys there is evidence of Quaternary sediment instability. The area is dissected by numerous erosional channels especially in the Kaipokok Valley. Recent slumps and slope failure are evident. At one location in the Kaipokok Valley, an estimated 26,000 m² of material slumped across the river after a period of heavy rain. Similar instability may also be expected in areas of the Kanairiktok Valley underlain by marine silts and clays.

Unit 6. Alluvium forms a minor constituent in the Kaipokok Valley where it is underlain by marine sediment.

Directional Indicators

Directions of ice flow range from northward to east-southeastward (Figure 4). There is an even distribution of striations exposed across the study area, a reflection of the distribution of bedrock.

The study area may be subdivided into at least 3 subareas based on ice-flow directions. North of the Kanairiktok Valley and northeast of Copper Pond, a northeastward flow predominates (055° to 070°). This is commonly the only one recorded. South of the Bruce Lake–Stipec Lake valley, a north-northeastward flow dominates (020-040°), and again is commonly the only flow recorded. The remaining area has complex flow patterns. The youngest flow is eastward and overprints a northeastward ice flow. Although this eastward paleoflow is noted across the study area, its major area of influence is west, north and south of Moran Lake. Farther east it is restricted altitudinally and laterally, and is often seen as a faint overprinting on well-developed northeastward striae. The relationships here are often crosscutting, which suggests limited erosion. Around Moran Lake the age relationships are based on stoss and lee features; i.e., evidence of the earlier flow has been removed on stossed faces. The distribution of the eastward, north-eastward and north-northeastward striae suggests that they relate to regional events rather than local influences.

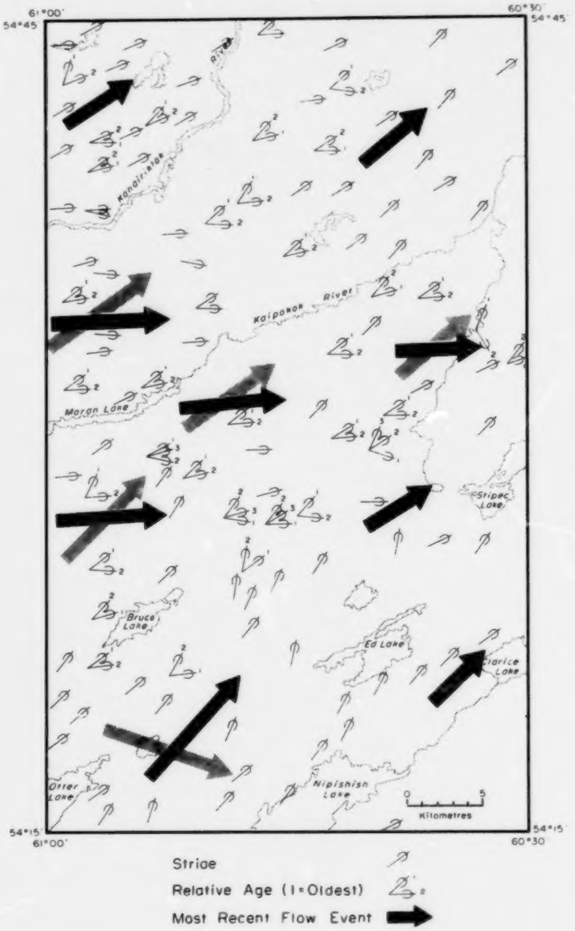


Figure 4. *Ice-flow-trend distribution. The map is based on erosional features, notably striae. Constructional landforms, where observed, are commonly oriented parallel to the most recent flow event.*

Apart from these major events, others are also evidenced. Between Otter Lake and Nipishish Lake, east-southeastward striae may reflect a component of a regional flow event identified south and west of Nipishish Lake by Thompson and Klassen (1986). To the east of Bruce Lake there is a series of northward-directed (000° to 010°) striae. The origin of these is speculative, although they are coincident with bedrock structure. Other striae are minor, locally-related features.

Clast Dispersal

The use of boulder tracing has been well documented in many heavily drift-covered areas and, in fact, in the Central Mineral Belt it has played a role in finding mineral deposits. The uranium discoveries at Moran Heights (Bayrock 1985), and the yttrium showings around Two-Tom Lake (Batterson and Miller, 1987) are two examples. In both cases, mineralized clasts were common. Usually, however, only a small number of clasts are discovered. To assist in detailing the distances and directions of transport in the Central Mineral Belt emphasis has been placed on tracing indicator lithologies. These distinctive rock types (about 1 in a 1000 can be easily spotted) have a discrete spatial distribution.

Several rock types have been used for boulder tracing in the Central Mineral Belt. These include Snegamook granite from north of Snegamook Lake; a green, aegerine gneiss from the Red Wine Alkaline Intrusive Suite near Letitia Lake; Seal Lake Group basalts (Thompson and Klassen, 1986); and also porcelanite from around Croteau Lake and a plagioclase porphyry from around Camel Lake (Batterson *et al.*, 1987). To this list can be added Crooked River granites that outcrop to the east and south of Nipishish Lake and a dolomite unit from the Moran Lake area.

Batterson *et al.* (1987) suggested that the presence of provenance indicators is related to their transportability (e.g., hard versus soft) and the number of clasts available for examination. At 20 km down-ice from their bedrock source, the probability of finding one indicator lithology out of 100 to 200 pebbles taken from a testpit is low. In the Moran Lake area, mudboils are common on upland surfaces, which are generally devoid of vegetation. The number of observed surface clasts and consequently the probability of locating indicator erratics is therefore increased.

The distribution of Red Wine alkaline rocks and Snegamook granite supports the findings of Thompson and Klassen (1986). Red Wine alkaline rocks are only found north and west of the eastern end of Moran Lake, and Snegamook granites are restricted in, and to the north of, the Kanairiktok Valley. The distribution of porcelanite and plagioclase porphyry produces the clearest dispersal patterns (Figure 5), and refines the comments of Batterson *et al.* (1987). Porcelanite clasts form a fan-shaped dispersal train within the study area. In the west the train is 7 km wide (between Moran Lake and Bruce Lake), whereas in the east the train is 20 km wide. A similar pattern is noted with the plagioclase porphyry dispersal train. At the western end the train is 3 km wide and in the central part of the study area it is 7 km. These patterns are consistent with the ice-flow-directional data. In the vicinity of Moran Lake eastward flow prevailed, whereas east of Moran Lake more northeastward paleoflow is indicated. The dispersal pattern reflects this change of glacial influence and the dispersal train 'dog-legs' accordingly. However, the ice-flow-pattern data suggest that eastward paleoflow extends to the central-eastern parts of the study area, although here it is likely that this influence is restricted to minor erosion rather than major deposition.

Glacial History: Some Preliminary Observations

Data derived from observations of the surficial environment have yet to be compared with radiometric, geochemical and grain-size data. Consequently, only a few speculative ideas are presented at this time.

The study area has undergone a complex glacial history, as evidenced by the variation of terrain types and ice-flow patterns. Reconciliation of these varied aspects is difficult, and fraught with pitfalls. Nevertheless, an attempt to do so shows that the glacial history can be interpreted in terms of three separate phases:

Phase 1 (Figure 6a). This is the period of maximum glacial activity. The area south of the Bruce Lake–Stipec Lake area was affected by a north-northeastward flow, whereas the area to the north was only affected by northeastward-flowing ice. It is not clear whether these events were contemporaneous, but the lack of conflicting glacial evidence and the dominantly unidirectional nature of the flow suggests that they were.

Phase 2 (Figure 6b). This corresponds to a period of deglaciation. The extent of the northeastward–north-northeastward flow event is unclear, although Batterson *et al.* (1987) noted its dominance in the Melody Lake area. However, during its retreat, the associated meltwater and the isostatically lowered coast allowed marine incursion. Marine sediments filled the Kaipokok Valley almost up to Moran Lake and are evident below outwash sediments in the Kanairiktok Valley. The level of deltas entering the Kaipokok Valley suggests marine level reached at least 125 m above sea level, with a major phase at about 105 m above sea level. The meltwater associated with retreat led to the deposition of outwash sediments in many valleys and the development of proglacial lakes; e.g., around Stipec Lake. It is likely that stillstands were associated with the deglacial trend. For example, the north and east shores of Nipishish Lake are till covered despite the fact that ice retreated downslope (i.e., southwestward) from Clarice Lake, and the intervening valley is outwash filled. It is likely that drainage was around the ice in Nipishish Lake and toward the south. A glaciofluvial veneer covers till in this area.

Phase 3 (Figure 6c). As well as stillstands it is likely that a separate pulse of ice was related to deglaciation. The Kanairiktok Valley has ice-contact outwash sediment overlying marine sediment. It is likely that this marine sediment was contemporaneous with that in the Kaipokok Valley because the marine limit is approximately the same. This late pulse produced the eastward-flow pattern in the western part of the study area. It is possible that this flow was less extensive in the central part of the area and more extensive in the Kanairiktok Valley. Ice-contact deposits (e.g., kettleholes and eskers) occur throughout the Kanairiktok Valley and even in the northern parts of the Kaipokok Valley. A series of gravel-rich ridges overlying marine sediment were noted in the Kaipokok Valley by Batterson *et al.* (1987), who assigned them to a marine origin. It is likely, however, that these features are eskers because they are an extension of eskers within the Kanairiktok Valley. Support for this idea of ice crossing the Kaipokok Valley comes from Thompson (personal communication, 1987), who observed southeastward-directed striae in this area. The orientation of the eskers is consistent with that of the Anna Lake valley. The suggestion that an ice tongue, related to that discussed above, pulsed down the Anna Lake valley is speculative.

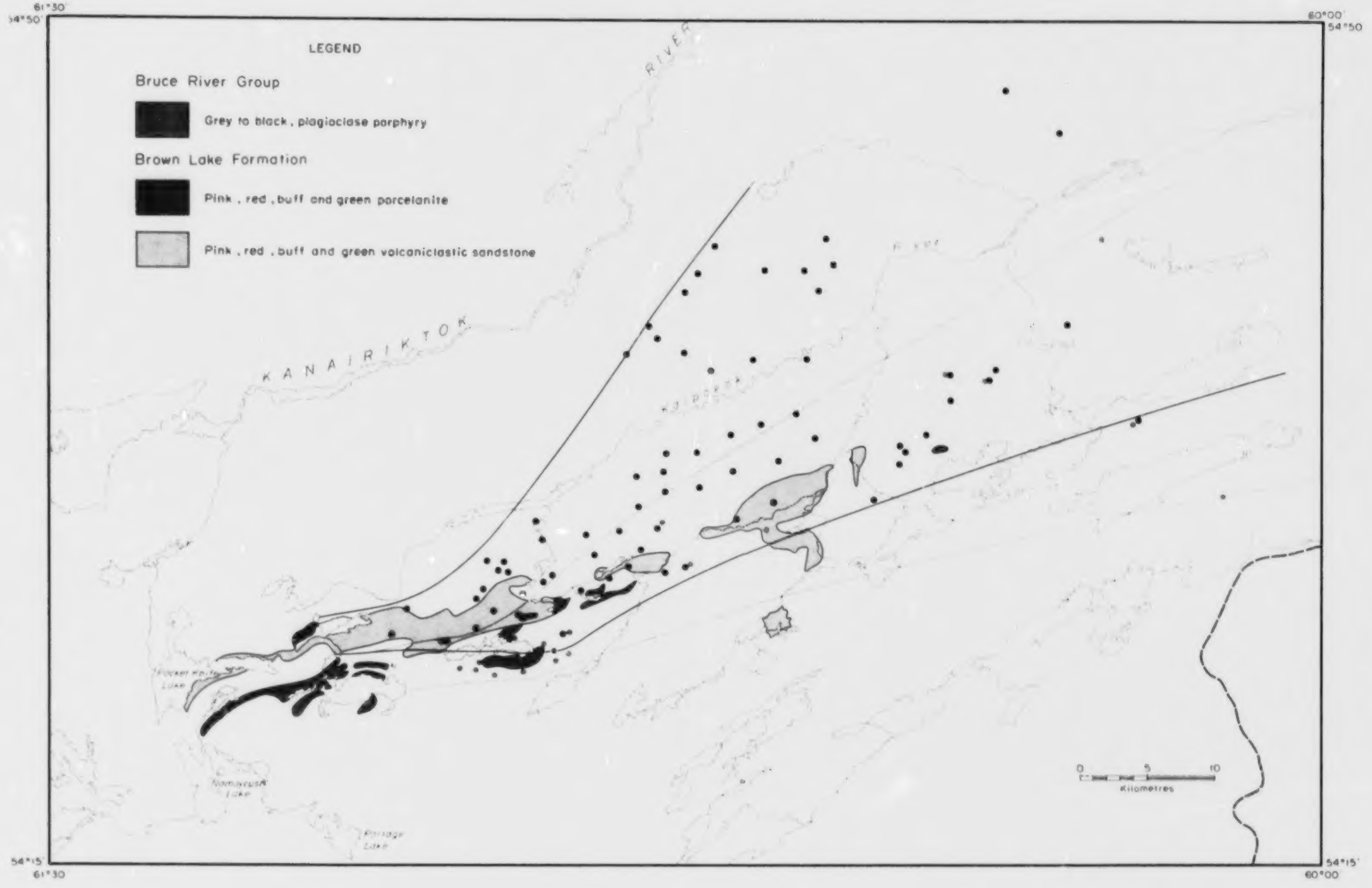

61°30'
54°50'
60°00'
54°50'
LEGEND
Bruce River Group
Grey to black, plagioclase porphyry
Brown Lake Formation
Pink, red, buff and green porcelanite
Pink, red, buff and green volcaniclastic sandstone
RIVER
KANAIRIKTOK
Pocket Knife Lake
Namaycush Lake
Portage Lake
0
5
10
Kilometres
54°15'
61°30
54°15'
60°00'

Figure 5. *Dispersal of indicator lithologies from the Bruce River Group and Brown Lake Formation. The occurrence of an indicator is shown as a dot the same shade as outcrop. Volcaniclastic sandstones of the Brown Lake Formation have similar characteristics to the porcelanite, which was mapped near Pocket Knife Lake. However, an unmapped porcelanite outcrop was discovered during the course of fieldwork, and other occurrences may be possible within the volcaniclastic suite.*

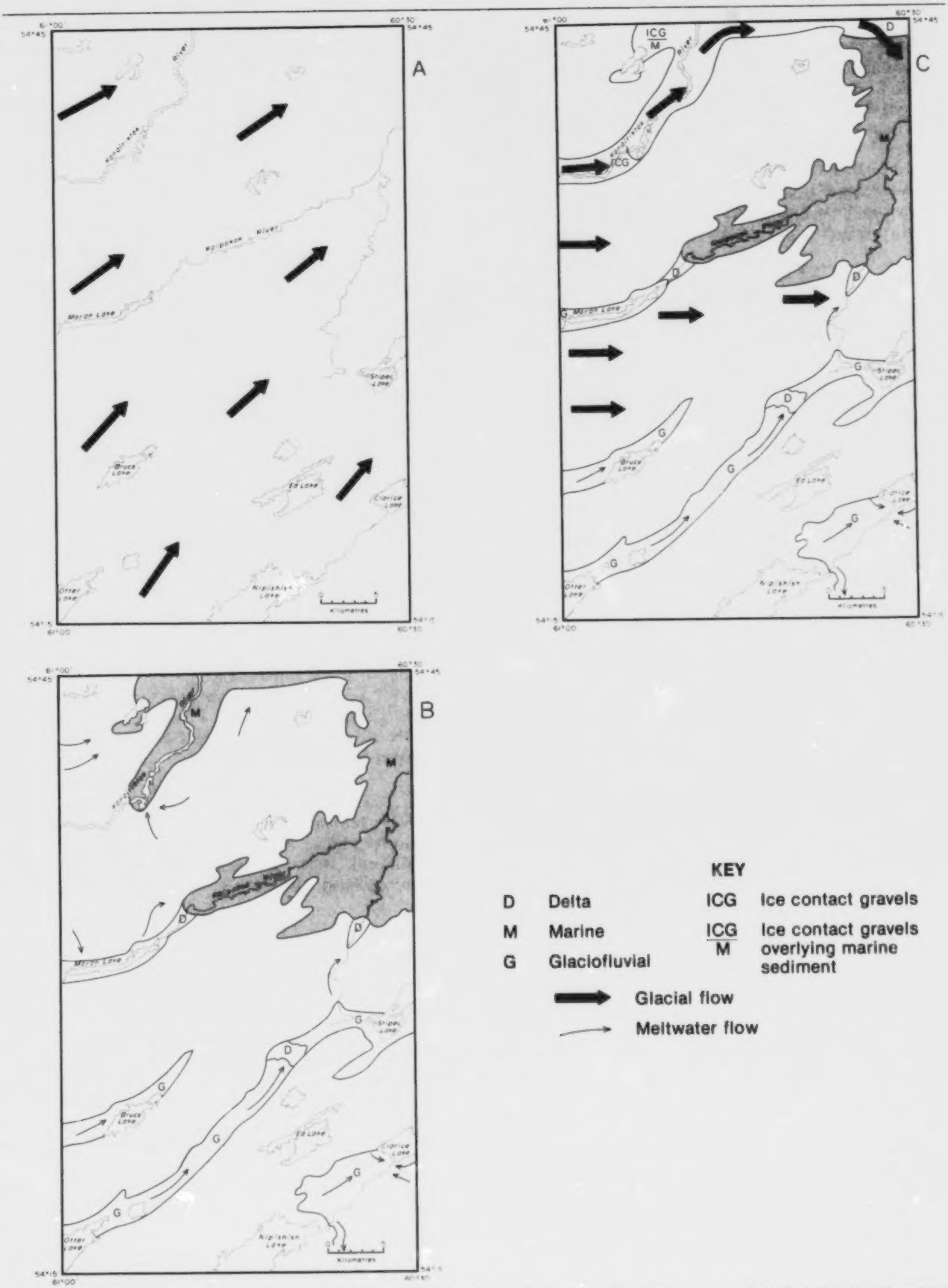

A
B
C
61°00
60°30
54°45
54°15
Kanairiktok River
Naskaupi River
Moran Lake
Stipec Lake
Bruce Lake
Ed Lake
Clarice Lake
Otter Lake
Nipishish Lake
Kilometres
ICG
M
D
G
KEY
D Delta
M Marine
G Glaciofluvial
ICG Ice contact gravels
ICG/M Ice contact gravels overlying marine sediment
Glacial flow
Meltwater flow

Figure 6. *Speculative phases in the glacial history of the Moran Lake area; model based on glacial striae, terrain mapping and sediment dispersal patterns.*

Many aspects of this suggested late pulse of ice are unresolved. For instance, are the marine sediments in the Kaipokok–Kanairiktok valleys contemporaneous? Is the eastward flow in the Moran Lake area related to the events in the Kanairiktok Valley? Is there supporting evidence from elsewhere? What are the mechanisms behind this pulse? What was the relationship between this pulse and sea level? Had sea level dropped by the time of the pulse? Further study in this area and others is needed to resolve the glacial history of this part of the Central Mineral Belt.

MINERAL EXPLORATION IMPLICATIONS

It has been demonstrated that the glacial history of the Moran Lake area is more complex than previously thought. Based on these findings, the earlier suggestions that drift prospecting is straightforward in central Labrador because of the simple configuration of the Laurentide ice sheet can be negated. There is evidence for two ice-flow events, based on dispersal of indicator lithologies; other ice flows are suggested by variation in orientation of ice-flow-directional indicators.

Drift-exploration programs in this part of Labrador should be restricted to areas underlain by till, and not areas of outwash, marine or lacustrine sediments. The processes by which till is deposited is better understood and more reliable in terms of dispersal, than other glacigenic sediment that may have undergone reworking and be far removed from its source.

SUMMARY

The level of understanding of the Quaternary environment of the Central Mineral Belt is steadily growing through a combined approach by provincial and federal government agencies. The current study has shown that previous interpretations of the Quaternary history in the Central Mineral Belt are too simplistic. Instead, early flows to the northeast and north-northeast have been identified, succeeded by a flow to the east that affected the western parts of the study area and altered dispersal patterns. The age and extent of this late flow is speculative, but may have followed the Kanairiktok Valley and covered the Kaipokok Valley to the west of West Micmac Lake.

This complexity of glacial events stresses the need for Quaternary mapping programs in areas of drift cover in the Central Mineral Belt of Labrador. It also highlights that failure to understand Quaternary environments may lead to erroneous conclusions in any drift-exploration program.

ACKNOWLEDGMENTS

The authors wish to thank Doug McIsaac for his assistance during the summer, and Phil Hillier who kept us and our visitors well supplied with good food. Sealand Helicopters Limited is thanked for its good service, and in particular Ted Hay, our pilot. Wayne Tuttle and Ken O'Quinn provided their usual high-quality expediting services. The manuscript was improved by reviews from David Proudfoot and Byron Sparkes.

REFERENCES

Banfield, C.E.
1981: The climatic environment of Newfoundland. *In* The Natural Environment of Newfoundland Past and Present. *Edited by* A.G. Macpherson and J.B. Macpherson. Department of Geography, Memorial University of Newfoundland, pages 83-153.

Batterson, M.J., Taylor, D.M. and Vatcher, S.V.
1985: Quaternary mapping and drift exploration in the Strange Lake area, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 85-1, pages 4-10.

Batterson, M.J. and LeGrow, P.
1986: Quaternary exploration and surficial mapping in the Letitia Lake area, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 257-265.

Batterson, M.J., Scott, S. and Simpson, A.
1987: Quaternary mapping and drift exploration in the eastern Central Mineral Belt, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 1-9.

Batterson, M.J. and Miller, R.R.
1987: A new Y-Nb-Be showing in the western part of the Central Mineral Belt, Labrador. Newfoundland Department of Mines, Mineral Development Division, Open File. [13L/1(66)]

Bayrock, L.A.
1985: Moran Heights Uraniferous Erratics fan. *In* Hopfengaertner, F., Assessment Report, Part I, Central Mineral Belt, Labrador. Saarberg Interplan Incorporated. [13K(166)].

French, H.M.
1976: The Periglacial Environment. Longman, London, 309 pages.

Fulton, R.J.
1986: Surficial geology, Red Wine River, Labrador, Newfoundland. Geological Survey of Canada, Map 1621A, scale 1:500,000.

Greene, B.A.
1974: An outline of the geology of Labrador. Newfoundland Department of Mines and Energy, Information Circular No. 15, 64 pages.

Klassen, R.A.
1983: A preliminary report on drift prospecting studies in Labrador. *In* Current Research, Part A. Geological Survey of Canada, Paper 83-1A, pages 353-355.

1984: A preliminary report on drift prospecting studies in Labrador, Part II. *In* Current Research, Part A. Geological Survey of Canada, Paper 84-1A, pages 90-97.

Lopoukhine, N., Prout, N.A. and Hirvonen, H.R.
1977: The ecological land classification of Labrador: a reconnaissance. Ecological Land Classification Series, Number 4, Fisheries and Environment Canada, 85 pages.

Macpherson, J.B.
1981: The development of vegetation of Newfoundland and climatic change during the Holocene. *In* The Natural Environment of Newfoundland: Past and Present. *Edited by* A.G. Macpherson and J.B. Macpherson. Department of Geography, Memorial University of Newfoundland, pages 189-217.

Moore, J.C.G.
1954: Report on the Kaipokok River concession area, Labrador. Unpublished report, AMCO Exploration Incorporated. [13K (7)]

Prest, V.K., Grant, D.R. and Rampton, V.N.
1968: Glacial Map of Canada, 1:5,000,000 scale. Geological Survey of Canada, Map 1253A.

Rogerson, R.J.
1982: The glaciation of Newfoundland and Labrador. *In* Prospecting in areas of glaciated terrain. *Edited by* P.H. Davenport. Canadian Institute of Mining and Metallurgy, pages 37-56.

Ryan, A.B.
1984: Regional geology of the central part of the Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Mineral Development Division, Memoir 3, 185 pages.

Thompson, F.J. and Klassen, R.A.
1986: Ice flow directions and drift composition, central Labrador. *In* Current Research, Part A. Geological Survey of Canada, Paper 86-1A, pages 713-717.

Vanderveer, D.G.
1986: Quaternary mapping/drift prospecting, Moran Heights, Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 267-269.

Wardle, R.J.
1987: Platinum-group-element potential in Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 211-223.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines
Mineral Development Division, Report 88-1, pages 343-355

PLACER POTENTIAL OF FOX ISLAND RIVER AND EAST-CENTRAL PORT AU PORT BAY: A PRELIMINARY ASSESSMENT

Margot Emory-Moore, Steve Solomon and Dennis Dunsmore
Centre for Cold Ocean Resources Engineering
Memorial University, St. John's, Newfoundland

ABSTRACT

Surficial-sediment texture, mineralogy and geochemistry are used to assess the potential for chromitiferous placers in Fox Island River and east-central Port au Port Bay, western Newfoundland. The geological setting of the study area constitutes a glaciated region which is characterized by the four criteria necessary for heavy-mineral placer formation: a source (Lewis Hills ophiolite), liberation mechanism (Pleistocene glaciation), conduit (Fox Island River), and sink (Port au Port Bay). Heavy-mineral distribution in the river, the coastal beaches and in the offshore reflect varying hydraulic regimes and the character of primary- and secondary-sediment sources. The highest heavy-mineral concentrations are found in beach sediments as discrete laminae and in modern marine sands; the lowest concentrations are found in the aggrading portions of the river mouth.

Conceptual models are formulated to trace the dispersal path of chromite and associated heavy minerals in both the fluvial- and coastal-offshore zones. Proglacial outwash bars, raised beaches and raised marine terraces warrant further investigation.

INTRODUCTION

A placer deposit is a concentration of economically valuable detrital mineral grains which are formed by surface or near-surface mechanical processes (most commonly running water). Placer minerals include 'heavy heavy minerals' (specific gravity 6.8-21), such as native gold, native platinum and cassiterite; the 'light heavy minerals' (specific gravity 4.2-5.3), chromite, rutile, ilmenite, zircon and monazite; and the gem minerals (specific gravity 2.9-4.1), diamonds, rubies and sapphires (Emery and Noakes, 1968). Placer deposits have historically provided a major share of the world's gold, platinum, diamond, ilmenite, rutile, zircon, and tin.

Despite their economic importance, there has been little sedimentary research in placer genesis (Slingerland and Smith, 1986). This is particularly true in glaciated terrains where the effects of glacial and glacially influenced sedimentary processes on placer formation are poorly understood. The site chosen for the present research (i.e., Fox Island River—Port au Port Bay, western Newfoundland; Figure 1) was extensively glaciated during the Quaternary, and is characterized by the four geological criteria necessary for placer formation:

1) source—ophiolitic rocks containing chromite and platinum-group elements (PGE),
2) liberation mechanism—glacial, periglacial, and postglacial processes resulting in the mechanical attrition of bedrock and contemporaneous dispersal and deposition of large volumes of sediment,
3) conduit (transport pathway)—Fox Island River and associated tributaries, and
4) depositional sink—Port au Port Bay.

The objective of the present study is to assess the placer potential of Fox Island River and Port au Port Bay. Longer term research objectives are:

1) the development of a preliminary genetic model for fluvial and marine placer formation in a glaciated terrain, and
2) delineation of favourable sites for further work.

GEOLOGY OF THE SOURCE ROCKS

The suite of rocks represented in the Fox Island River drainage basin include (Williams, 1975):

1) inliers of Precambrian basement
2) an autochthonous Cambro-Ordovician carbonate succession
3) a Middle Ordovician allocthonous clastic shelf succession and ophiolitic suite, and

---

This project is a contribution to the Canada-Newfoundland Mineral Development Agreement, 1984-1989

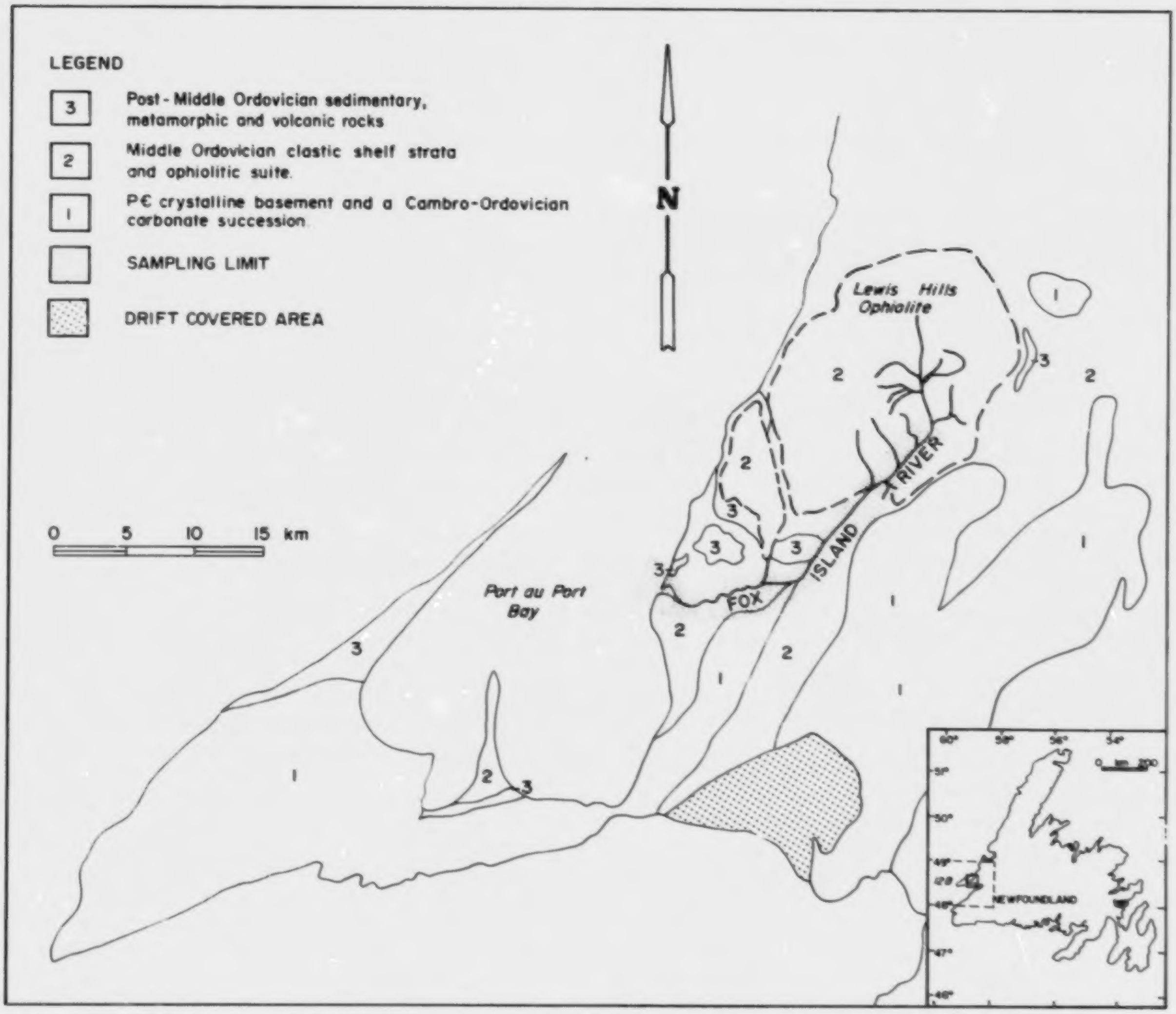

LEGEND
3 Post-Middle Ordovician sedimentary, metamorphic and volcanic rocks
2 Middle Ordovician clastic shelf strata and ophiolitic suite.
1 P€ crystalline basement and a Cambro-Ordovician carbonate succession.
SAMPLING LIMIT
DRIFT COVERED AREA
N
0 5 10 15 km
Lewis Hills Ophiolite
RIVER
ISLAND
FOX
Port au Port Bay
1
2
3
NEWFOUNDLAND

Figure 1. *Location and geological setting of the study area.*

4) neoautocthonous schists, volcanic rocks and Carboniferous cover rocks.

Within the present study area, the Lewis Hills ophiolitic rock suite forms the highest structural slice in a series of stacked thrust sheets, which are interpreted to record the evolution and destruction of the ancient continental margin of North America (Williams, 1975). Discrete lithologic assemblages (e.g., harzburgite and wehrlite) within the ophiolite are characterized by numerous discontinuous layers of disseminated and massive chromite. Chromite grains are generally euhedral to subhedral, <2 mm in diameter, and grade at approximately 36−52 weight percent Cr_2O_3 in the richest sections (Snelgrove, 1934; Dunsworth *et al.*, 1984).

The geological significance and economic potential of platinum-group elements (PGE) in ophiolitic complexes have recently received considerable attention (e.g., Legendre and Auge, 1986). Although no economic lode deposits have been discovered, platiniferous placer deposits are known to occur in association with ophiolitic suites (Ford, 1981). Given the known, albeit very low-grade occurrences of PGE in the Lewis Hills ophiolite (Page and Talkington, 1984), there exists a potential for associated PGE-bearing placer deposits within the study area.

QUATERNARY GEOLOGY: LIBERATION MECHANISM AND SECONDARY SOURCE

Glacial, periglacial and postglacial processes are of considerable importance to the liberation of placer minerals due to their effects on bedrock attrition and overall sediment availability. Glaciated terrains are generally characterized by a regolith of mechanically weathered debris, which is the product of subglacial quarrying and abrasion, erosion by running water, and freeze−thaw activity. These processes release large volumes of sediment ranging in size from <63 micrometres to house-sized boulders.

Within the study area, maximum ice extent during the late Wisconsin was very near present coastal limits (Grant, 1977). Of the three glacial rock-stratigraphic units recognized in southwestern Newfoundland, only the Robinson's Head Drift occurs in the study area (Brookes, 1974). This unit is considered to be a product of a local ice readvance (12,600 ± 140 yrs. B.P.), and is characterized by a sheet of coarse till (Brookes, 1974).

Sediments exposed in the incised river banks of Fox Island River and in wave-cut terraces along coastal sections reveal a complex sequence of Quaternary events. Facies types identified include (no chronological ordering): diamictons (basal till and/or resedimented morainal material), pro- and postglacial colluvial, fluvial and deltaic sands and gravels, and raised marine silts and clays.

Isostatic readjustment subsequent to the late Wisconsin recession resulted in a 60 m drop in relative sea level dating from 14,000 to 6,000 yrs. B.P. Relative sea level has risen about 14 m from 6,000 yrs. B.P. to present (Brookes *et al.*, 1985).

A CHARACTERIZATION OF THE CONDUIT AND SINK

Given the source (Lewis Hills ophiolite and glacial sediments) and a liberation mechanism (glacial- and postglacial-mechanical weathering), an attempt was made to further characterize the transport corridor (Fox Island River) and depositional sink (Port au Port Bay). To this end, a detailed surficial mapping and sampling program with select geophysical profiling was undertaken; a description of field and analytical procedures and preliminary results follow.

Methodologies

Mapping and Sampling Program. Surficial sediments from the bed of Fox Island River, the beaches adjacent to the river and in the offshore zone (<20m water depth) fronting the river mouth were mapped and sampled for textural and mineralogical analyses. A total of 312 surficial samples (average weight of 1 kg) were collected: 35 in Port au Port Bay, 25 from the coastal beach and 252 from Fox Island River. Representative samples from major glacial sequences were collected from incised river banks and wave-cut terraces. Finally, three bulk samples (weighing about 30 kg) from the beach sediment, glacial outwash and diamicton were collected for analyses of noble metals.

All river samples were collected on a coarse line grid of 250 m with sample intervals of 100 m. The samples were restricted to the <4 mm size fraction as the very coarse cobble–boulder lag that characterizes the river bed precluded any form of bulk sampling for textural analysis. The potential loss of fines resulting from subaqueous sampling in the river was minimal due to low water conditions, which allowed sampling of exposed riverbed sediments.

Offshore surficial grab samples were collected by scuba divers on a coarse line grid of 1 km with sample intervals of 250 m. Sample positioning, accurate to within ± 50 m, was determined by fin and compass. A hand trowel was used for collection of offshore samples. Depth limitations on scuba divers restricted sample collection to <20 m water depth.

Two graduated marker posts were inserted in the seabed and will be used to monitor net sediment erosion and/or deposition. A washer, placed over the marker rod, will drop to the depth of deepest erosion (this is important given that diver observation of the rods is not possible during storms, when deepest erosion is expected to occur). The rods will be examined every six months to coincide with induced seasonal variations.

Geophysical Program. The geophysical program consisted of VLF–resistivity, hammer refraction, seismic and sonic subbottom profiling surveys. The total VLF–resistivity coverage was 1.9 km using 10 m stations (Figure 2). A dual channel Huntec system with a source-receiver station of 2 m was used in the collection of 0.5 km of seismic data (Figure 2). Each of the two geophones were used separately over the same area and then both used simultaneously in a reverse profile; this repetition was required for the detection of dipping or ghost layers in the subsurface.

A Raytheon 1000X dual frequency subbottom profiler was used in the nearshore area off the mouth of Fox Island River. Approximately 5 km of line were surveyed. The quality of the data was poor because the acoustically hard seabed in the area (coarse sands and gravels) caused considerable scattering of the signal and a generally incoherent response.

Laboratory Analysis. Analyses of samples were selective and based on the criteria of uniform geographic spacing and inferred geomorphic controls (i.e., where flow velocity variations occur within the river). Twenty riverbed, three beach, and thirty-three offshore samples were chosen for textural analyses. Samples were dried, split and sieved through a bank of seven sieves measuring 0.063 mm, 0.106 mm, 0.25 mm, 0.5 mm, 1.0 mm, 2.0 mm and 4.0 mm.

Heavy-mineral separation of both the 0.063 mm to <0.25 mm and >0.25 mm to <1.0 mm size fractions were carried out on 19 offshore samples, 2 beach samples, and 44 river samples using a combination of gravity and centrifuge techniques. In addition, the 0.063 mm to <0.106, the 0.106 mm to <0.250 mm, and the 0.250 mm to <0.500 mm size fractions of one offshore, one beach, and one riverbed sample were individually separated in order to identify any mineralogical partioning by size. Polytungstate, a nontoxic, water-soluble heavy liquid (specific gravity of about 2.8), was used in all heavy-mineral analyses.

Petrographic examination of selected heavy residues was complimented by energy dispersive X-ray analyses of constituent mineral species. DCP emission spectrometry (performed on a contractual basis by Nuclear Activation Services Limited) was used for total metal analyses of the

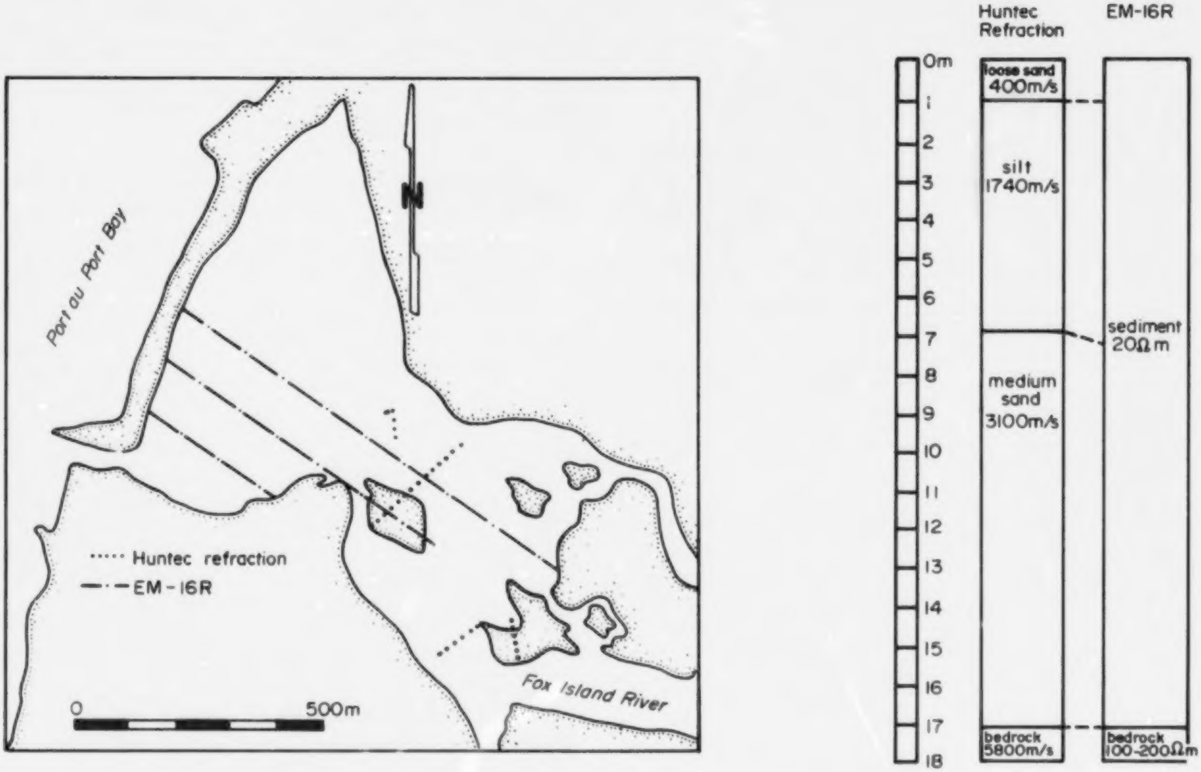


Figure 2. *Location and interpreted stratigraphy of the geophysical profiles; m/s is metres per second; Ω m is ohm-metres.*

sand (0.063 mm to 1.0 mm) fraction of 30 samples. Analyses of noble metals by ICP mass spectrometry is underway.

Results and Interpretation

Geophysics. Four stratigraphic horizons, as determined through graphic velocity calculations of seismic traces, were identified near the mouth of Fox Island River. An interpretation of sediment lithology (Figure 2), is based on velocity ranges for known sediment types. The resistivity data did not provide the necessary differentiation of sedimentary horizons, but did confirm the depth to bedrock.

Facies Characterization. The Fox Island River–Port au Port Bay system consists of three general depositional environments: offshore, beach, and river. Each environment is characterized by discrete facies types of which six have been delineated on the basis of textural character, *in situ* visual descriptions and spatial distribution; facies O1, O2, and O3 are found in the offshore zone; facies B1 and B2 characterize the beach deposits; and facies R1 characterizes Fox Island River sediments.

Facies O1 occurs in water depths >10 m (Figure 3). It consists of well-sorted, medium sand with <3 weight percent gravel and no clay or silt. Ephemeral current ripples and abundant sand dollars are present. Facies O1 is interpreted to represent modern marine sands undergoing active transport through the influence of waves and tidal currents.

Facies O2 is a poorly sorted, sandy gravel found in water depths ranging from <15 m to the intertidal zone (Figure 3). The sand component of this facies, ranging in content from 18 weight percent to 67 weight percent is generally entrapped within gravel–cobble interstices. Cobbles range up to 8 cm in diameter and are generally well-rounded. The gravel bed is inhabited by a variety of flora and fauna, suggesting overall gravel immobility. On this basis, facies O2 may be interpreted to represent a wave-reworked, lag deposit derived from glacial sediments.

Facies O3 is a well-sorted, medium sand which blankets gravel and cobbles (Figure 3). This facies is found in water depths of <3 m, and is restricted in occurrence to the lee side of a protruding subaqueous sand spit. This suggests deposition by longshore currents.

Facies R1 is found within the confines of the Fox Island River and is characterized by a surficial pebble–cobble lag armour with interstitial sands and isolated sand lenses. A general trend of decreasing boulder–cobble size downriver is observed with many local variations related to changes in

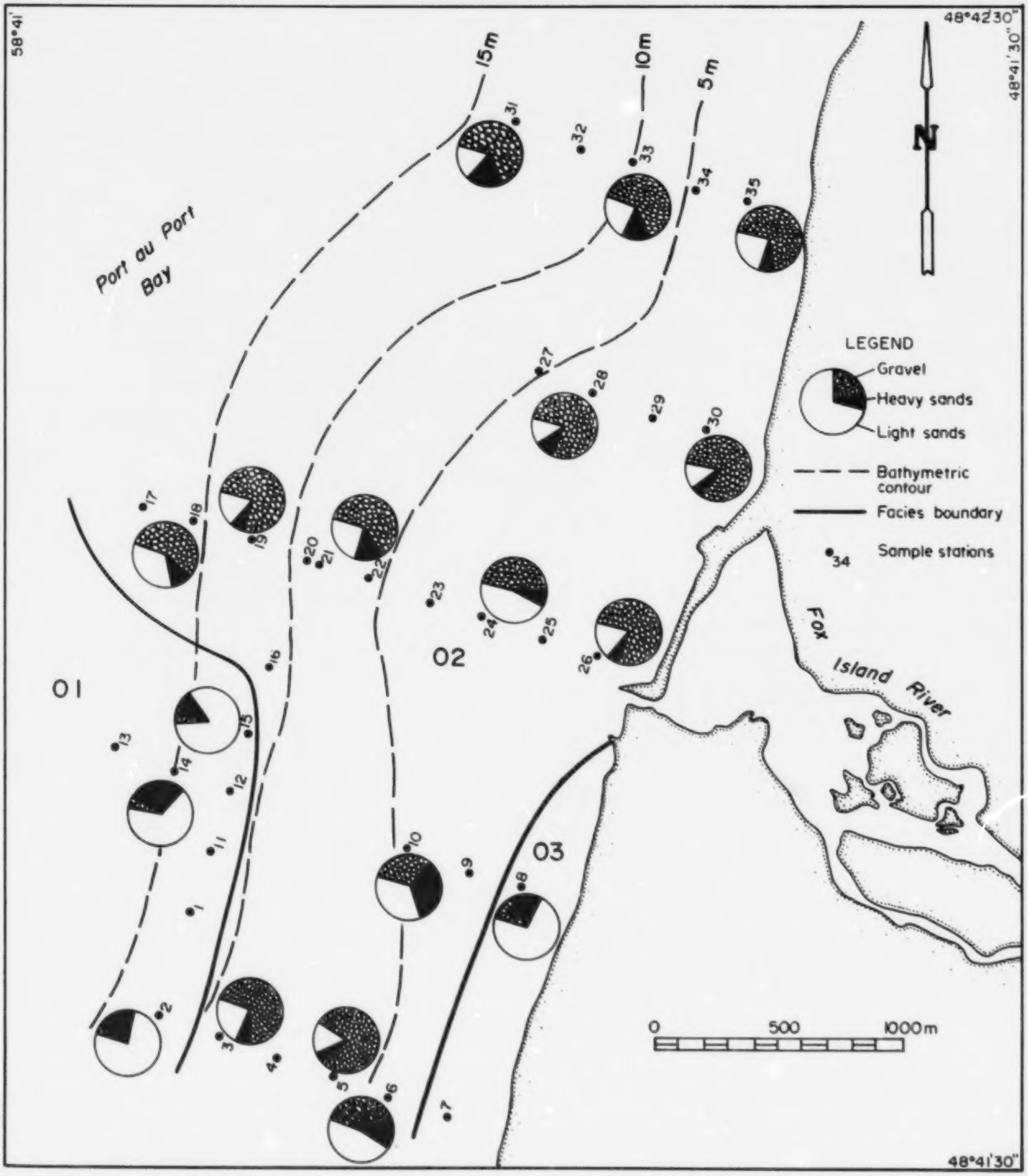

58°41'
48°42'30"
48°41'30"
48°41'30"
15m
10m
5m
N
Port au Port Bay
LEGEND
Gravel
Heavy sands
Light sands
Bathymetric contour
Facies boundary
Sample stations
34
O1
O2
O3
Fox Island River
0
500
1000m
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35

Figure 3. *Textural facies distribution and heavy-mineral abundances in east-central Port au Port Bay.*

bedrock lithology, presence of talus slopes and character of the incised glacial sediments. Grain-size distributions of the <4 mm size fraction vary unsystematically downriver. Near the mouth of the river, facies R1 is dominated by sands and gravels that form elongate bars with superimposed current ripples.

Facies B1 is characterized by unimodal, well-sorted supratidal sands. Facies B2 is defined by a moderately sorted, intertidal pebble armour.

Heavy Minerals. The heavy-mineral suite within the study area is mineralogically immature, consisting of, in order of decreasing abundance: opaques, garnet, pyroxene, amphibole, olivine, rutile, zircon, staurolite and epidote. Textural constraints on mineralogy include:

1) an increase in total heavy-mineral content with decreasing grain size,

2) an increase in the abundance of zircon and opaques with a decrease in grain size and,

3) a decrease in the abundance of olivine with a decrease in grain size.

Preliminary examination of the opaque minerals (through energy dispersive X-ray analysis) reveals an abundance of chromite (20-40 weight percent of the opaque minerals) followed by magnetite, ilmenite and minor sulphide phases. Cr_20_3 content of the chromite varies between 35-55 weight percent.

The spatial variation of heavy-mineral concentrates within the sand fraction (0.063 mm to 1.00 mm) of the offshore, beach, and river facies is illustrated in Figures 3 and 4. Within facies R1 sediments, heavy-mineral abundances decrease downriver, probably reflecting both distance from source (Lewis Hills ophiolite) and increased dilutional effects of aggradational processes in the lower reaches of the river. In contrast, the upper river is dominated by erosional processes which serve to enhance heavy-mineral enrichment through entrapment of grains in gravel interstices (Figure 4).

The supratidal beach sediments (facies B1) are characterized by discrete heavy-mineral laminae with concentrations reaching 98 total weight percent (Figure 4). Heavy-mineral-rich laminae range in thickness from 2 mm to 10 mm and are separated by 10 mm to 100 mm of clean quartzofeldspathic sand. These heavy-mineral occurrences are typical of beach placers, and generally result from grain segregation within bedflow during wave backwash, and in this case, during storm events. Heavy-mineral concentrations within the intertidal zone (facies B2) are much less, averaging 18 weight percent.

The concentration of heavy minerals detected in one analyzed sample of facies O3 (see Figure 3) was 18 total weight percent. This concentration may have formed through either differential entrainment (i.e., selective transport of light grains resulting in a residual lag of heavy minerals) or selective grain settling. Facies O3 sands are present only as a very thin surface veneer.

Facies O2 sediments exhibit a large variation in heavy-mineral content, ranging from 4 total weight percent to 32 total weight percent. Anomalous concentrations of heavy minerals probably formed as a result of lag entrapment within gravel interstices. The cause of the unsystematic heavy-mineral distribution may be attributed to local variations in cobble–boulder size coupled with spatial variabilty in sediment supply.

Facies O1 exhibits the highest overall heavy-mineral content (excepting the supratidal beach) ranging up to 32 total weight percent. The operative enrichment process is probably differential entrainment through wave and tidal reworking.

Geochemistry. The relative concentrations of Cr, Fe, Mg and Ti in the sand fraction (0.063 mm to 1.00 mm) of select offshore and river sediments are listed in Table 1; normalized plots illustrating the spatial distribution of these elements are provided in Figures 5a and 5b. Several observations can be made:

1) Mg and Ti content in the river sediments reflect local changes in bedrock lithology; Mg decreases away from the Lewis Hills ophiolite, Ti increases downriver where volcanic and metasedimentary rocks predominate;

2) Cr content of the river and offshore sediments varies unsystematically and is spatially correlative with Fe, reflecting the high Fe and Cr content of spinels;

3) within the offshore sediments, all element concentrations are less variable (Table 1), reflecting more uniform enrichment processes and minimal primary source-related biases.

An analysis of a discrete heavy-mineral laminae within the supratidal beach zone (facies B1) assayed 67,000 ppm Cr, 130,000 ppm Fe, 40,000 ppm Mg and 5,200 ppm Ti. In contrast, a bulk sample from the intertidal sediment (facies B2) assayed 310 ppm Cr, 41,0000 ppm Fe, 45,000 ppm Mg and 1,600 ppm Ti.

DISCUSSION: A GENETIC MODEL FOR PLACER DEVELOPMENT

The distribution and preservation of heavy-mineral placer deposits is dependent on temporal variations in depositional environments and overall sediment availability. Exploration strategies for heavy-mineral placers in the present study area, and in glaciated terrains as a whole, require that genetic models be formulated to trace the dispersal path of placer minerals. For the purpose of the present study, a sequence of simplified conceptual models are presented in an attempt to trace the contemporaneous dispersal of chromite and

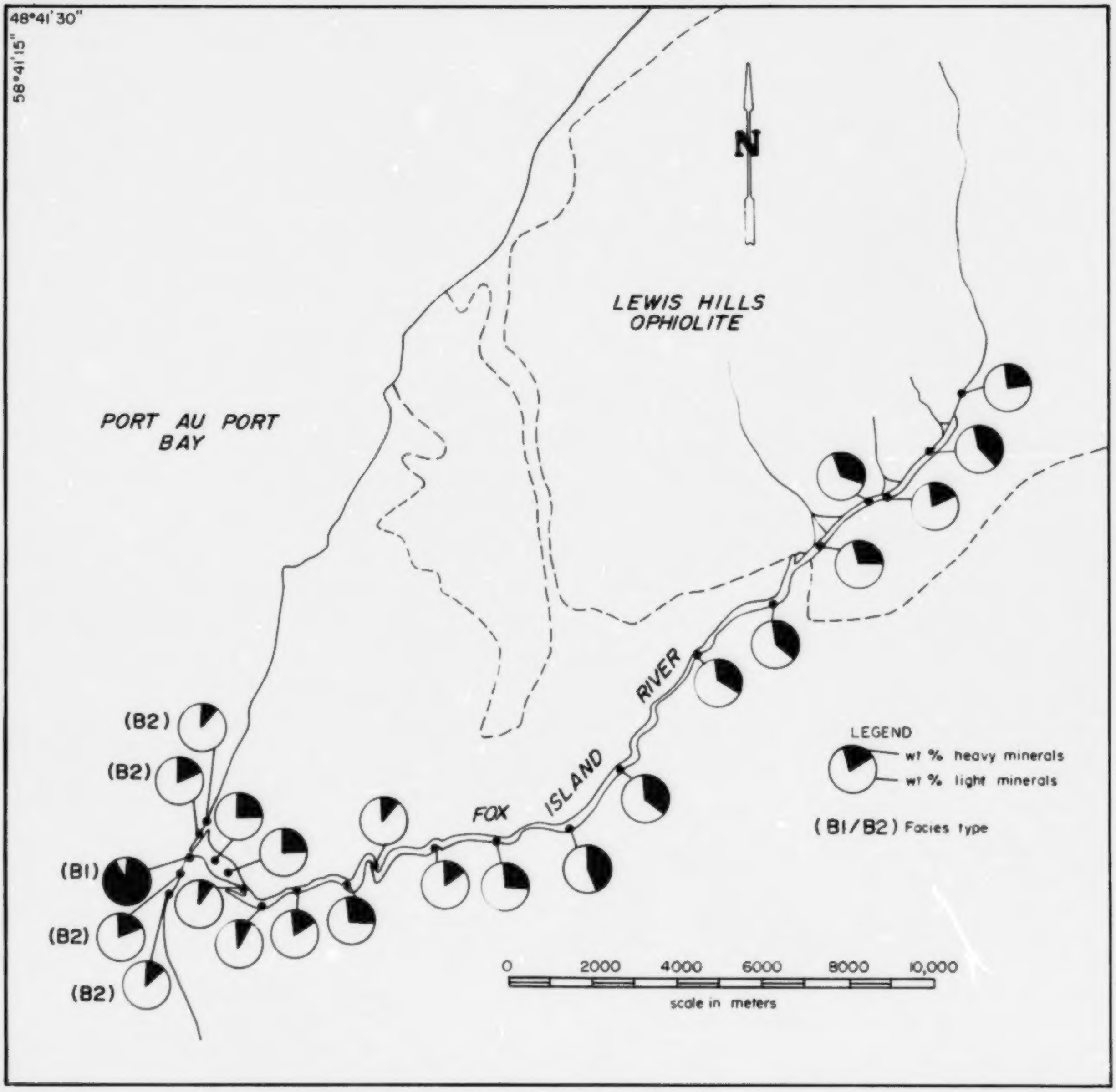

48°41'30"
58°41'15"
PORT AU PORT BAY
LEWIS HILLS OPHIOLITE
N
FOX ISLAND RIVER
(B2)
(B2)
(B1)
(B2)
(B2)
LEGEND
wt % heavy minerals
wt % light minerals
(B1/B2) Facies type
0
2000
4000
6000
8000
10,000
scale in meters

Figure 4. *Heavy-mineral abundances (0.065 mm to 1.00 mm sand fraction) in Fox Island River and the adjacent coastal beach.*

Table 1. Sediment geochemistry

	Cr		Fe		Mg		Ti	
	river	offshore	river	offshore	river	offshore	river	offshore
minimum (ppm)	750	1,800	48,000	44,000	62,000	52,000	30	1,000
maximum (ppm)	18,000	6,500	83,000	55,000	210,000	83,000	1,200	1,500
average (ppm)	5,000	3,583	59,867	49,500	139,733	67,917	481	1,266
C. V. (%)	87	38	16	6	40	15	96	16

C. V. – coefficient of variation

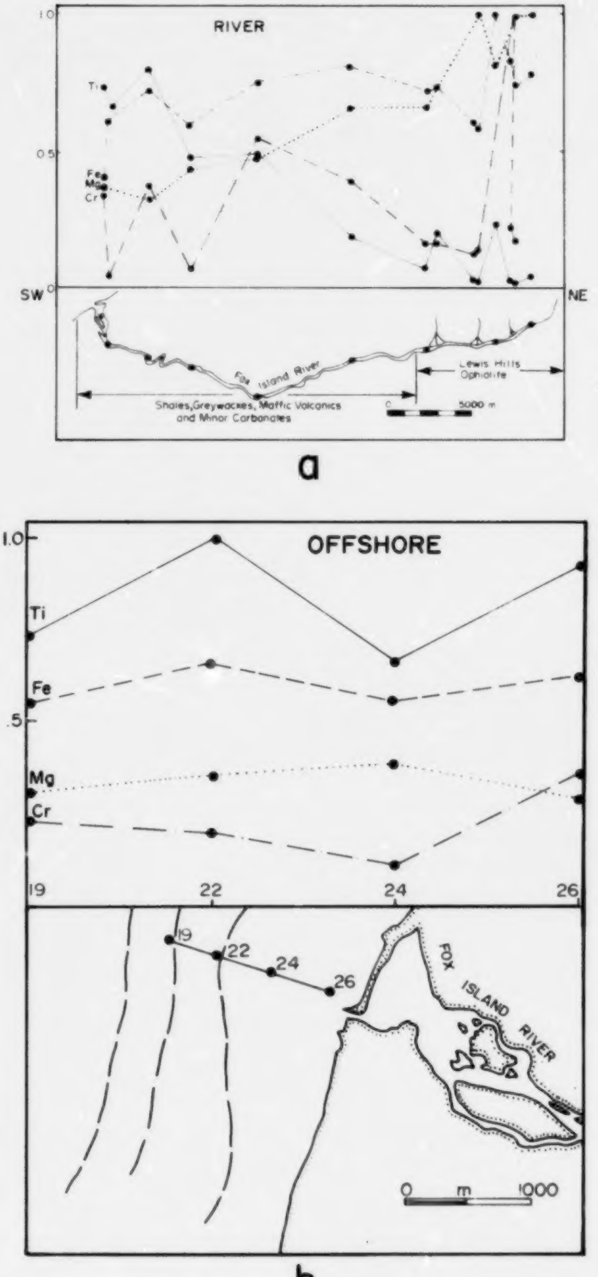


Figure 5. *Normalized plots of the spatial distribution of Ti, Cr, Fe and Mg, in Fox Island River (a) and in east-central Port au Port Bay (b).*

associated heavy minerals in both the fluvial (Figures 6 to 8) and coastal–marine (Figures 9 to 11) environments. The models are based primarily on reported glacial style (Brookes, 1974; Grant, 1977), sea-level history (Brookes *et al.*, 1985), observed field relations and initial sediment analysis as presented in this report. Model assumptions include:

1. the study area was characterized by alpine-style glaciation that was confined to the major trunk valley (as supported by the observed local dipsersal of pebbles and by the model proposed by Grant, 1977),
2. the maximum areal extent of late Wisconsin ice was near present coastal limits and occurred at approximately 14,000 yrs. B.P. (Grant, 1977),
3. the late Wisconsin relative sea-level maximum occurred at approximately 14,000 yrs. B.P. (Brookes *et al.*, 1985), and
4. relative sea-level minimum occurred at approximately 6,000 yrs. B.P. (Brookes *et al.*, 1985).

The conceptual models, presented in Figures 6 to 11, illustrate and describe the effects of deglaciation and isostatic rebound on the stratigraphy and placer potential of fluvial and marine deposits within the present study area.

CONCLUSIONS

The textural, mineralogical and geochemical character of the surficial sediments within Fox Island River and east-central Port au Port Bay reflect the spatial variability inherent in differing depositional environments and in the type and relative contribution of sediment sources (e.g., glacial, fluvioglacial, marine). An accurate assessment of the placer potential in the study area cannot yet be made due to limited sample coverage, incomplete sample analysis (particularly with respect to PGE) and the lack of information upon which estimates of grades and tonnages can be based. Mineral commodities of interest include chromite, platinum, aggregate and heavy-mineral byproducts (e.g., zircon, rutile). Based on the available data, the strongest heavy-mineral potential appears to be in the modern supratidal beach sediments where concentrations reach 98 total weight percent including approximately 7 total weight percent chromic oxide. Of further interest is facies O1 marine sands where modern concentrating mechanisms are operative and thick sand accumulations are likely to occur.

Potential zones of placer development and targets for further work may also include proglacial outwash bars, raised beach deposits and raised marine terraces. Modern fluvial placers are unlikely to occur in the upper river due to high-energy flooding and removal of most sand-sized sediment from the major trunk valley. Sediment in the lower river may contain isolated zones of placer enrichment, although none were identified in the present study.

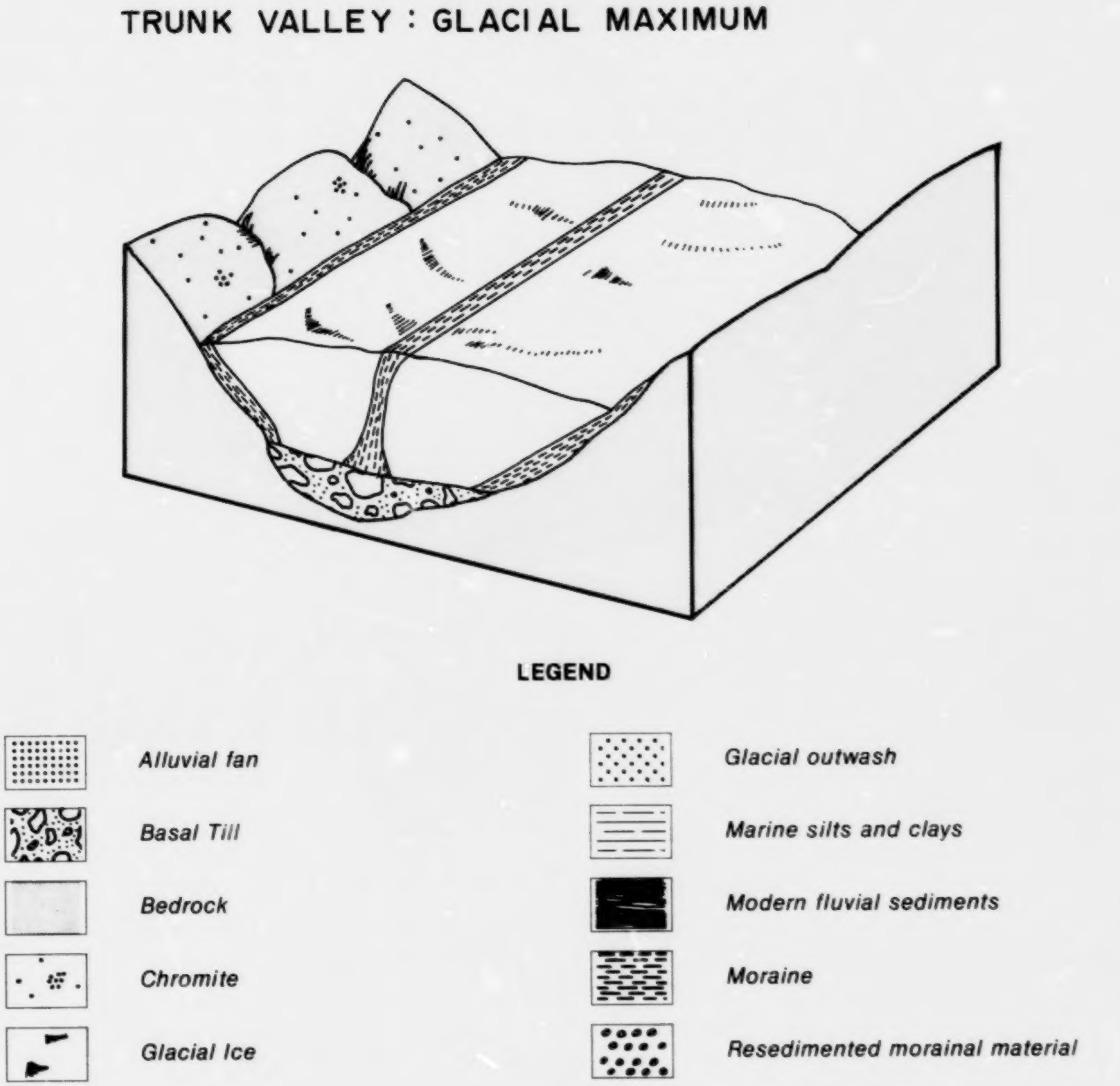

TRUNK VALLEY : GLACIAL MAXIMUM
LEGEND
Alluvial fan
Basal Till
Bedrock
Chromite
Glacial Ice
Glacial outwash
Marine silts and clays
Modern fluvial sediments
Moraine
Resedimented morainal material

Figure 6. *Valley glaciation during the late Wisconsin (14,000 yrs. B.P.) characterized by ice scouring and dispersal of chromitiferous bedrock (i.e., the Lewis Hills ophiolite) and pre-existing sediment. Tills and morainal deposits formed. Placer deposits, if present, confined to basal tills and lateral moraines (where mutual attrition of particles is high) and occur close to source (e.g., New Zealand; Henley and Adams, 1979). Glacial tills and moraines commonly act as intermediate collectors providing ample low-grade material for postglacial reworking.*

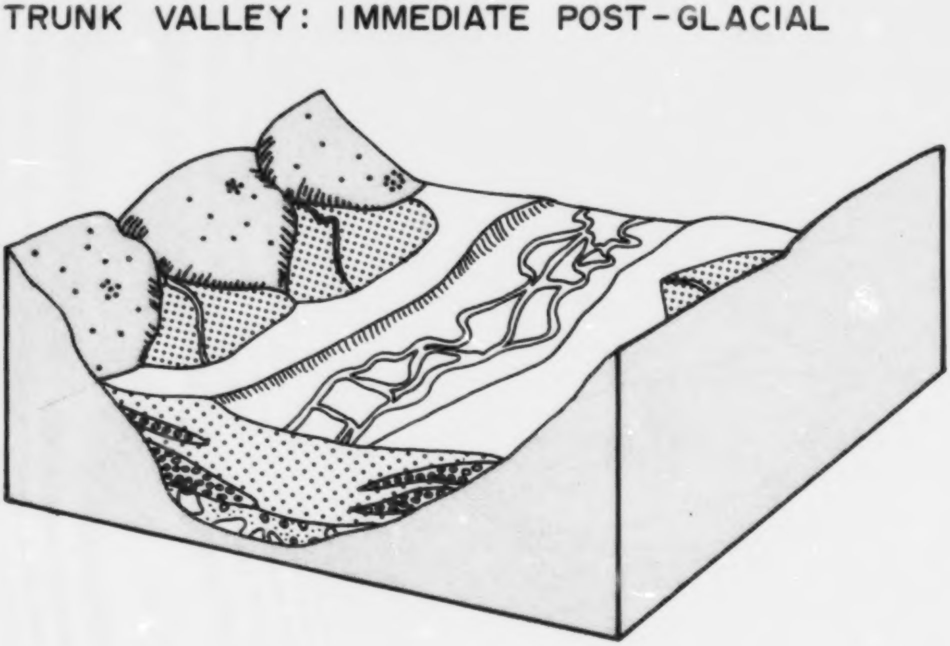


Figure 7. *Contemporaneous deposition of resedimented morainal material and glaciofluvial outwash as glacier recedes upvalley (about 14,000 yrs. B.P.). Sediment is rapidly aggraded with localized and probably very minimal sediment reworking. Placers are unlikely. (See Figure 6 for legend.)*

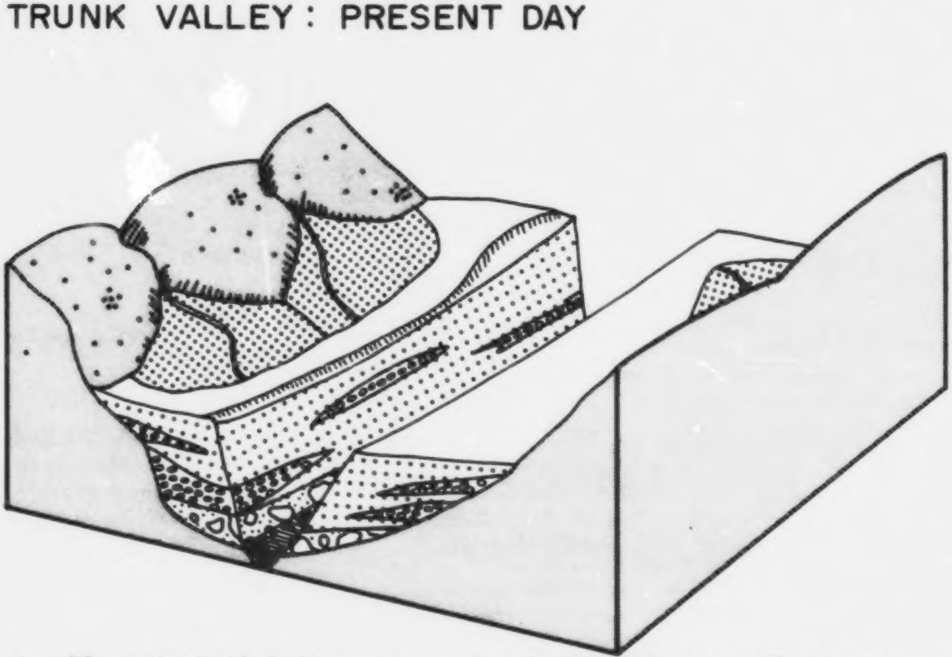


Figure 8. *Isostatic uplift associated with the ice recession results in base-level lowering and fluvial incision of aggraded glacial sediments (6,000 yrs. B.P.). Fluvially transported material is flushed from the valley and deposited near the mouth of the Fox Island River and in Port au Port Bay. Placer accumulations, if present, are localized and the product of either lag entrapment within gravel interstices, or selective grain settling in response to a marked decrease in flow velocity (e.g., pockets behind boulders). Large placer deposits are unlikely due to the overall paucity of sand-sized material. (See Figure 6 for legend.)*

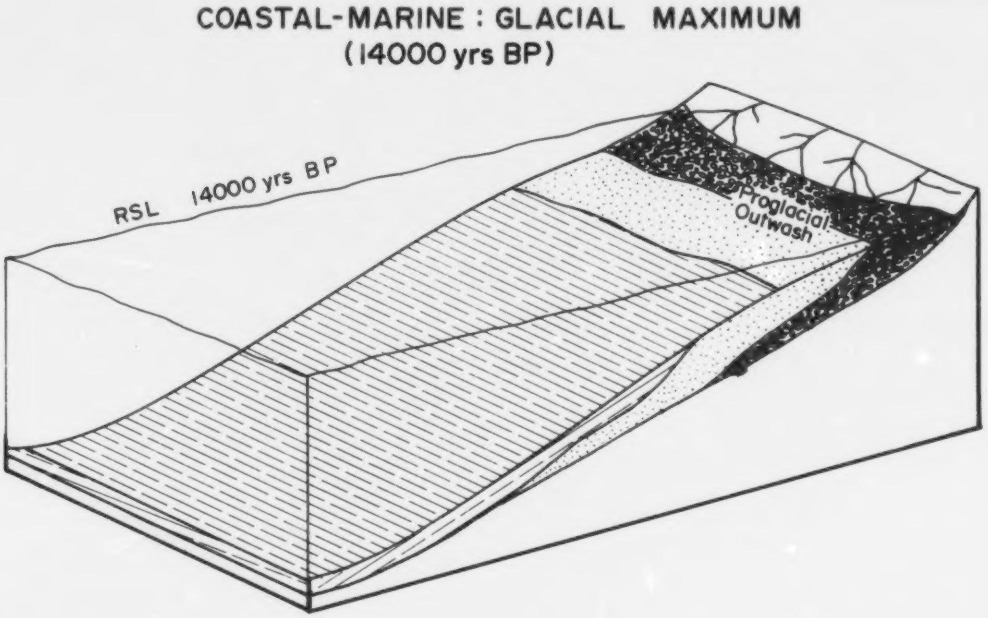

COASTAL-MARINE : GLACIAL MAXIMUM
(14000 yrs BP)
RSL 14000 yrs BP
Proglacial Outwash

Figure 9. *Proglacial deposition and braid delta construction during the sea-level highstand (about 14,000 yrs. B.P.). Deposits generally fine downslope and fine upsection (as a result of a retreating glacial source) (cf. Miall, 1983). Some lateral variation (not illustrated) is expected as distributary channels migrate across the outwash front. Heavy-mineral enrichment within discrete sand facies may occur in submarine channels, in zones of wave reworking, and in subaerial outwash on the sandur face (e.g., Baffin Island; Emory-Moore, 1986). In general, sediments aggrade rapidly with limited opportunity for reworking. Placers will thus be low grade and not a prime exploration target. (See Figure 6 for legend.)*

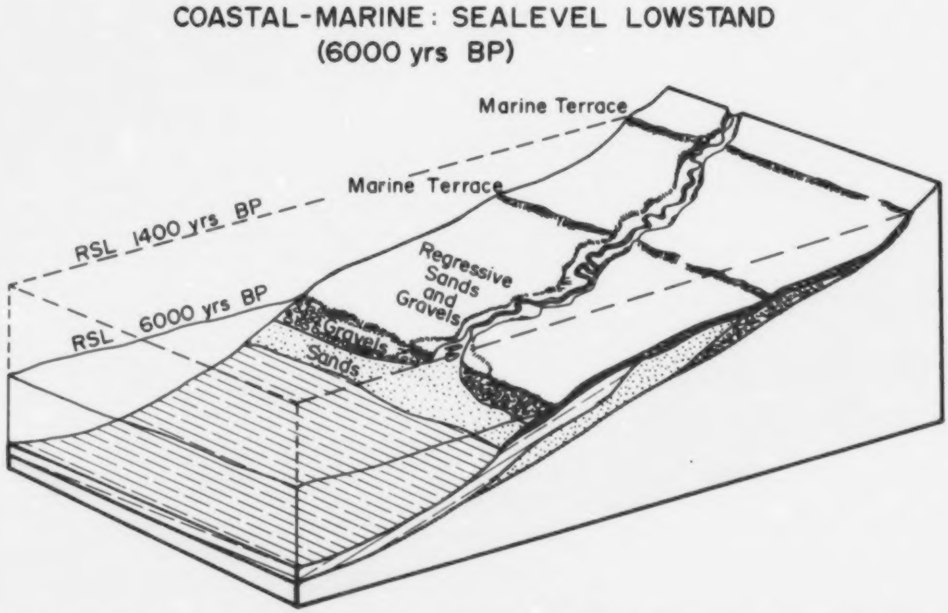

COASTAL-MARINE : SEALEVEL LOWSTAND
(6000 yrs BP)
Marine Terrace
Marine Terrace
RSL 1400 yrs BP
Regressive Sands and Gravels
RSL 6000 yrs BP
Gravels
Sands

Figure 10. *Sea-level regression from about 14,000 yrs. B.P. to 6,000 yrs. B.P. with a lowstand at approximately 15 m below present sea level. Outwash deposits reworked to form a residual sand and gravel lag. Marine stillstands are marked by wave-cut terraces where heavy minerals may be locally enriched (e.g., Oregon, U.S.A.; Griggs, 1945). The relatively rapid rate of sea-level regression in the study area (approximately 0.75 mm per yr.) may have precluded the development of mature planation surfaces and associated placer deposits. (See Figure 6 for legend.)*

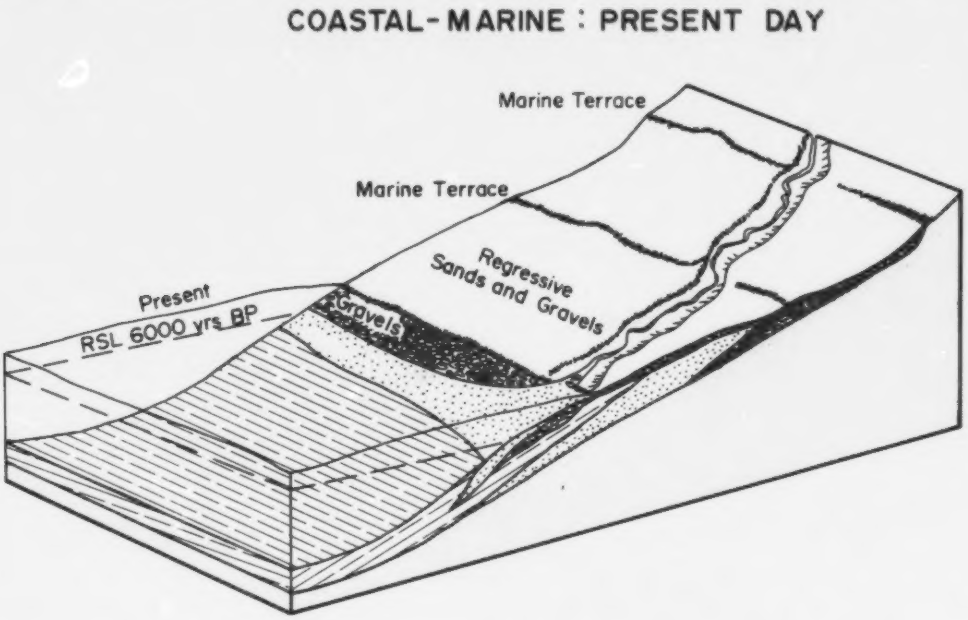


Figure 11. *A marine transgression from 6,000 yrs. B.P. to present with onlap of beach and offshore sands and gravels. Sediment sources include reworked proglacial outwash units and modern discharge from the Fox Island River. Wave and tidal reworking may selectively concentrate heavy minerals in the beach and offshore zones (e.g., Oregon, U.S.A.; Griggs, 1945 and northern British Columbia, Canada; Barrie* et al., in preparation). *(See Figure 6 for legend.)*

ACKNOWLEDGMENTS

We wish to acknowledge the following people for their assistance and support: M. Batterson for manuscript review; D. Cameron and D. Squires for scuba work; D. Christian, G. Fitzgerald and L. Clarke for their able field and logistical support; S. Dunsworth for a geological tour of the Lewis Hills ophiolite complex; B. Jones of Fox Island River for accomodations and entertainment; D. King for drafting; C. Morrissey for sample analysis; D. Proudfoot for active field participation and manuscript review and; W. Shilts (GSC) for use of the Raytheon subbottom profiler. This research is jointly funded under the Mineral Development Agreement and the Centre for Cold Ocean Resources Engineering.

REFERENCES

Barrie, J.V., Emory-Moore, M., Luternauer, J. and Bornhold, B.
In preparation: Origin of modern heavy mineral deposits, northern British Columbia Shelf. Submitted to Marine Geology.

Brookes, I.A.
1974: Late-Wisconsin glaciation of southwestern Newfoundland (with special reference to the Stephenville map-area). Geological Survey of Canada Paper 73-40, 31 pages.

Brookes, I.A., Scott, D.B. and McAndrews, J.H.
1985: Postglacial relative sea-level change, Port au Port area, west Newfoundland. Canadian Journal of Earth Sciences, Volume 22, pages 1039-1047.

Dunsworth, S., Calon, T. and Malpas, J.
1986: Structural and magmatic controls on the internal geometry of the plutonic complex and its chromite occurrences in the Bay of Islands Ophiolite, Newfoundland. *In* Current Research. Geological Survey of Canada, Paper 86-1A, pages 471-482.

Emery, K.O. and Noakes, L.C.
1968: Economic placer deposits of the continental shelf. Economic Comm. Asia and Far East, Technical Bulletin, Volume 1, pages 95-111.

Emory-Moore, M.
1986: Textural and mineralogical characteristics of nearshore sediments, eastern Baffin Island. Centre for Cold Ocean Resources Engineering (Memorial University of Newfoundland, St. John's, Newfoundland), Publication No. 86-2, 55 pages.

Ford, R.J.
1981: Platinum-group minerals in Tasmania. Economic Geology, Volume 76, pages 498-504.

Grant, D.R.
1977: Glacial style and ice limits, the Quaternary stratigraphic record, and changes of land and ocean level in the Atlantic provinces, Canada. Géographie Physique et Quaternaire, Volume XXXI, pages 247-260.

Griggs, A.B.
1945: Chromite-bearing sands of the southern part of the coast of Oregon. United States Geological Survey, Bulletin 945-E, 150 pages.

Henley, R.W. and Adams, J.
1979: On the evolution of giant gold placers. Institution of Mining and Metallurgy, pages B41-B50.

Legendre, O. and Auge, T.
1986: Mineralogy of platinum-group mineral inclusions in chromitites from different ophiolitic complexes. *In* Proceedings of the conference Metallogeny of Basic and Ultrabasic Rocks. *Edited by* R.A. Gallagher, R.A. Ixer, C.R. Neary and H.M. Prichard. The Institution of Mining and Metallurgy, pages 361-375.

Miall, A.D.
1983: Glacial fluvial transport and deposition. *In* Glacial Geology—An Introduction for Engineers and Earth Scientists. *Edited by* N. Eyles. Pergamon Press, New York, pages 168-183.

Page, N.J. and Talkington, R.W.
1984: Palladium, platinum, rhodium, ruthenium and iridium in peridotites and chromitites from ophiolite complexes in Newfoundland. Canadian Mineralogist, Volume 22, pages 137-149.

Slingerland, R. and Smith, N.
1986: Occurrence and formation of water-laid placers. Annual Review of Earth and Planetary Sciences, Volume 14, pages 113-147.

Snelgrove, A.K.
1934: Chromite deposits of Newfoundland. Department of Natural Resources, Bulletin Number 1, St. John's, Newfoundland.

Williams, H.
1975: Structural succession, nomenclature, and interpretation of transported rocks in western Newfoundland. Canadian Journal of Earth Sciences, Volume 12, pages 1874-1894.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 357-365

QUATERNARY GEOLOGY OF THE MOUNT SYLVESTER (2D/3) MAP AREA

David N. Proudfoot
Quaternary Geology Section

ABSTRACT

The Quaternary geology of the Mount Sylvester (2D/3) map area was completed during 1987. The study is aimed at providing a basis for drift exploration. It contains terrain that is dominated by glacigenic units: 1) ridges oriented transverse to glacier-flow direction, 2) ridges streamlined parallel to glacier flow, 3) hummocks and ridges, 4) hummocks, 5) boulder fields, 6) organic plains, and 7) colluvial fans and aprons. These units are arranged so that 1 to 3 above occur in zones that are transitional, one to another, in a down-ice direction. This distribution is closely associated with major bedrock units. Unit 4 is distributed across the map area and is superimposed upon most other glacial features.

Only one glacier-flow direction (170° ± 10°) has been preserved in the area. The surface material of the entire area down to a depth of about 1 m is less compact and contains less fines than the underlying till. Transverse- and streamlined-ridge features are interpreted to have been deposited subglacially, and are likely composed of mainly local material, whereas sediment in hummocky terrain is interpreted to have been deposited from an englacial position and is likely of more distant origin. Therefore, sampling for drift-exploration purposes should be directed at subglacially deposited parts of the terrain.

INTRODUCTION

This project was initiated in the Bay d'Espoir area (Figure 1) in 1987 as the beginning of a regional study to provide a framework for drift prospecting. The area was chosen because of its high mineral potential and the problems of unknown glacial-flow history and extensive areas of drift and bog cover. It also provides an opportunity to interact with current bedrock-mapping projects and active private-sector, mineral-exploration programs, and offers the possibility of stimulating new exploration. Prior to this study, there was no Quaternary mapping carried out in the area. However, Jenness (1960) extended his generalized map of the distribution of late Pleistocene glacial features into the area (inner and outer drift zones). Systematic Quaternary mapping, including sedimentology, geomorphology, pebble lithology and ice-flow direction studies, provides the basis for this work.

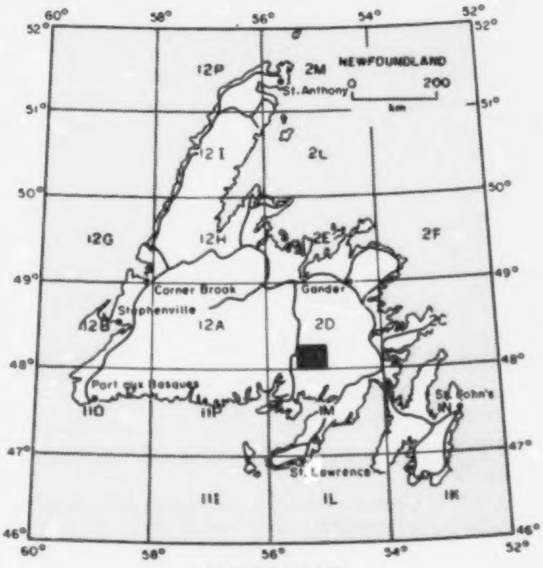
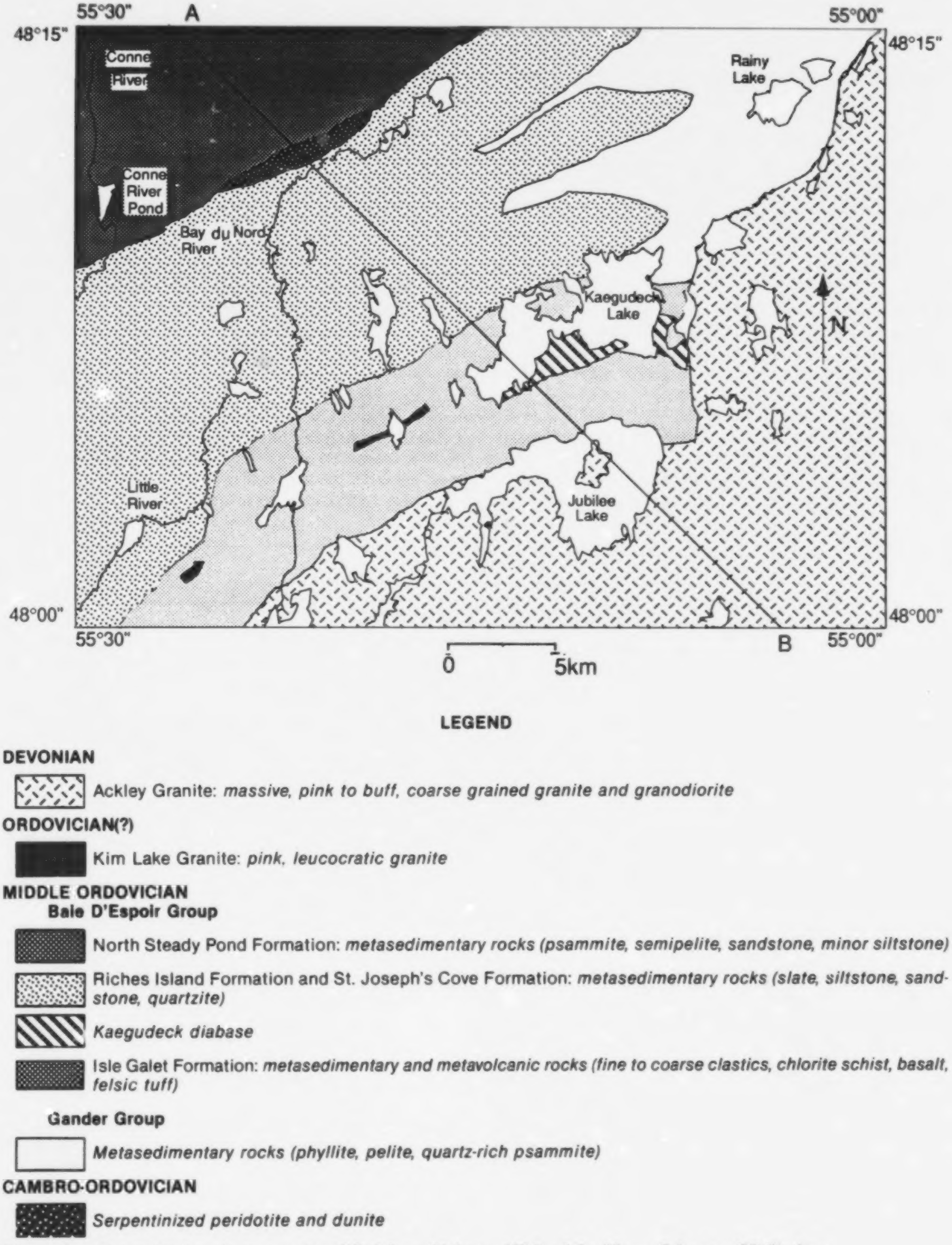


Figure 1. *Location of the study area.*

Regional Setting

The Mount Sylvester map area (Figure 2) is located in east-central Newfoundland about 25 km northeast of Milltown, Bay d'Espoir. Geologically (Figure 2), the northeastern part of the area is underlain by metasedimentary rocks (quartz-rich psammite, phyllite and pelite) of the Gander Group (Dickson, 1983, 1986, 1987). The metasedimentary and metavolcanic rocks (fine- to coarse-grained clastics, chlorite schist, basalt, felsic tuff) of the Isle Galet Formation (Baie d'Espoir Group) cut across the central part of the area. The north-central and northwest parts of the area are underlain by rocks of the Riches Island, St. Joseph Cove and North Steady Pond formations of the Baie d'Espoir Group (slate, sandstone, siltstone, felsic tuff, pelite, quartzite, conglomerate, diabase, psammite, semipelite). The Ackley Granite underlies the southeastern part of the map area.

The area contains gold showings mainly within felsic volcanic rocks near Kim Lake (Figure 3) (McHale, 1985, 1986) and a number of base-metal showings (Bay du Nord


55°30"
A
55°00"
48°15"
48°15"
Conne River
Conne River Pond
Bay du Nord River
Rainy Lake
Kaegudeck Lake
N
Little River
Jubilee Lake
48°00"
48°00"
55°30"
B
55°00"
0
5km

LEGEND

DEVONIAN

▨ Ackley Granite: *massive, pink to buff, coarse grained granite and granodiorite*

ORDOVICIAN(?)

■ Kim Lake Granite: *pink, leucocratic granite*

MIDDLE ORDOVICIAN

Baie D'Espoir Group

▩ North Steady Pond Formation: *metasedimentary rocks (psammite, semipelite, sandstone, minor siltstone)*

▒ Riches Island Formation and St. Joseph's Cove Formation: *metasedimentary rocks (slate, siltstone, sandstone, quartzite)*

▧ *Kaegudeck diabase*

▓ Isle Galet Formation: *metasedimentary and metavolcanic rocks (fine to coarse clastics, chlorite schist, basalt, felsic tuff)*

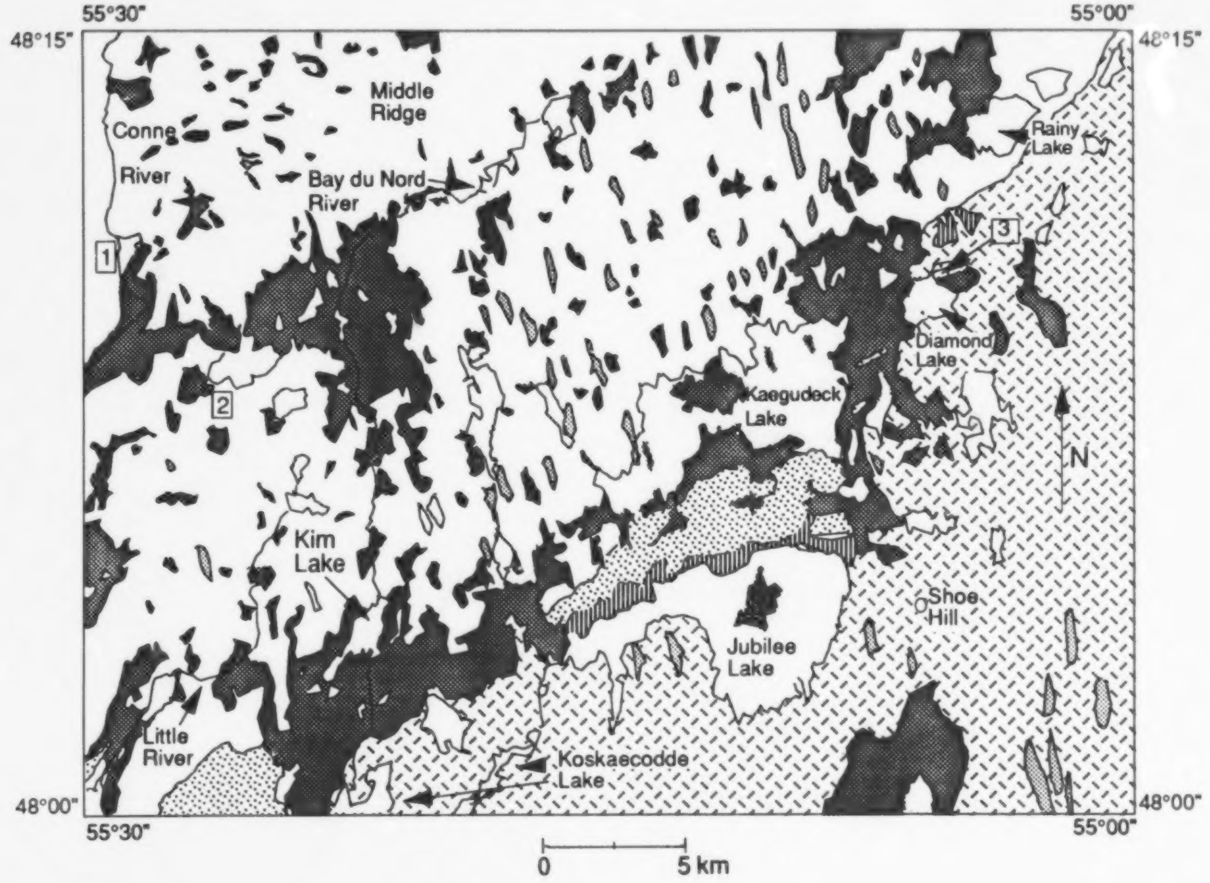
Gander Group

☐ *Metasedimentary rocks (phyllite, pelite, quartz-rich psammite)*

CAMBRO-ORDOVICIAN

▦ *Serpentinized peridotite and dunite*

Figure 2. *Generalized geology map (simplified from Dickson, 1986) of the Mount Sylvester (2D/3) sheet.*



POSTGLACIAL

▥ Colluvial fans and aprons: *diamicton (pebbly-silty sand), gravel and sand occurs along the base of steep slopes; formed by gravity processes on slopes (poor sampling medium)*

☐ Organic plain: *bog and fen; water saturated; organic accumulation is generally less than 1- to 4-m thick; (can be penetrated for sampling using hand auger)*

▩ Boulder field: *ground surface is covered with an armouring of subrounded to subangular boulders and cobbles of predominantly local origin; there are no fine sediments as matrix*

GLACIAL (PREDOMINANTLY) OUTWASH

▨ Terrain with pebbly and sandy hummocks and ridges: *areas of hummocky sandy till, sand and gravel; 5- to 15-m high; eskers in a few areas; well drained and poorly vegetated; (poor sampling medium)*

GLACIAL (PREDOMINANTLY TILL)

▦ Hummocky terrain: *single hummocks and hummocky zones (5- to 10-m high); contains mainly silty-sandy till with less than 20 percent sand and gravel (occurs mainly as lenses); sediment is 5- to 10-m thick in hummocks and 1- to 3-m thick between hummocks; typically forest or bog covered; deposited from englacial position; (sample compact massive till between hummocks)*

▒ Streamlined terrain: *subparallel linear ridges (crag and tails, flutes) 5- to 10-m high; mainly composed of compact, silty-sandy till; bedrock cores are common; typically forest covered; deposited subglacially parallel to ice flow; (sample compact massive till)*

■ Ridges transverse to ice-flow direction: *Rogen moraine, crescentic ridges, and an elongate irregular discontinuous ridge; all are 5- to 15-m high; contain mainly silty-sandy till; deposited from subglacial and englacial positions; (sample massive compact till at base of ridges)*

PREGLACIAL

░ Rock: *Areas of bare bedrock and small areas of thin discontinuous till and pebbly sand*

Figure 3. *Generalized Quaternary geology map of the Mount Sylvester (2D/3) sheet. Numbers refer to the following localities: 1) Conne River Pond, 2) Ontwanic Lake, and 3) Mount Sylvester.*

River, Kim Lake and Kaegudeck Lake areas) within the Isle Galet Formation. Scheelite mineralization occurs in greywackes in the northwestern part of the map area. Dickson (1987) presents details regarding the history of mineral exploration in the area.

QUATERNARY GEOLOGY

Field Methods

Mapping was accomplished by field-checking airphoto interpretations. Access by truck is limited to a small part of the northwest corner of the map area adjacent to the Bay d'Espoir highway because of extensive bog cover. The only natural exposures available for examination and sampling occur within this area along the Bay d'Espoir highway and a few logging roads. The remaining area was accessed by helicopter. Material checking and sample collection were mainly from hand-dug pits (1 m deep). A small helicopter-portable backhoe (Cricket Tow−All) capable of excavating to 2 m depth was also tested (Plate 1). It was found to be slower and, therefore, more expensive than by hand, but with modifications it may prove to be effective, especially in obtaining bulk samples beneath shallow bog-cover where manual digging is impossible.

Plate 1. *A helicopter-portable backhoe, shown here, is effective in obtaining bulk subsurface bog samples that are used for material and stratigraphic control.*

Map Description

Subdivision of the map area into Quaternary map units (Figure 3) is based on glacial and postglacial geomorphology. The map legend includes areas of bare rock and the predominant sediment types, geomorphic features, typical topographic relief and a generalized interpretation of sediment genesis. The sampling potential for drift exploration is listed in parentheses at the end of each map-unit description. Where possible, map units are numbered on a relative age basis such that older units have lower numbers. They are grouped into glacial (related to glaciers), glacial outwash (deposited by glacial meltwater) and postglacial (nonglacial units of postglacial age). For mineral-exploration purposes, most glacial deposits within the map area that are optimal for sampling are covered with trees or bog.

General Considerations

The Mount Sylvester map area straddles three major rock-stratigraphic packages,which form the main topographic elements of the area because of their differences in resistance to erosion (Figure 4). The affects of glaciation occur as streamlined rock surfaces, moraines and outwash features. Glacial landform complexes coincide with regional bedrock-controlled topographic features, and are arranged transverse to glacial flow (cf. Figures 2 and 3). Streamlined landforms and glacial striations on bedrock indicate that the predominant ice-flow direction in the area was to the south and south-southeast (170° ± 10°), cutting across the regional strike of the bedrock. In the northwest on Middle Ridge, crescentic ridges, Rogen- and hummocky-moraine are the only recognizable glacial features. Along the southern slope of Middle Ridge the glacial geomorphology changes to streamlined terrain (flutes, crag and tails) that is underlain by relatively less-resistant, predominantly metasedimentary and volcanic rocks of the Baie d'Espoir Group. Farther down-ice and to the east, along the northern margin of the Ackley Granite, hummocky moraine and outwash predominate. This regional, glacial geomorphic transition is discussed later in the paper.

Throughout this paper, advice regarding drift-sampling strategies is given. These recommendations are based largely on general theoretical considerations and may be invalid in some places (laboratory investigations in support of these hypotheses are ongoing). In particular, it is assumed that the higher the material is transported in a glacier, the more likely it is to have travelled farther than the sediment that underlies it. Therefore, it is suggested that, where possible, sediment that is interpreted to have been transported and deposited subglacially be sampled.

Bedrock

Mappable areas of bare rock occur mainly to the southeast of the zone of streamlined terrain especially south of Kaegudeck Lake. There are numerous outcrops throughout the area that are too small to map at 1:50,000 scale (see map by Dickson, 1987).

Ridges Transverse to Ice-Flow Direction

Terrain characterized by transverse ridges is restricted to the northwest part of the area on a topographic high that is underlain by psammite, semipelite and pelite of the North Steady Pond Formation and a small area of pre- Gander Group peridotite and dunite. Three forest-covered ridge features, composed of silty-sand diamicton (till-like sediment composed of a broad spectrum of grain sizes: from silt and clay to boulders) and having numerous boulders and cobbles resting on their surfaces, occur within this map unit: 1) Rogen moraine (Plate 2), which appear as flat-topped, scalloped elongate ridges in plan view, are 100- to 1000-m long, 50- to

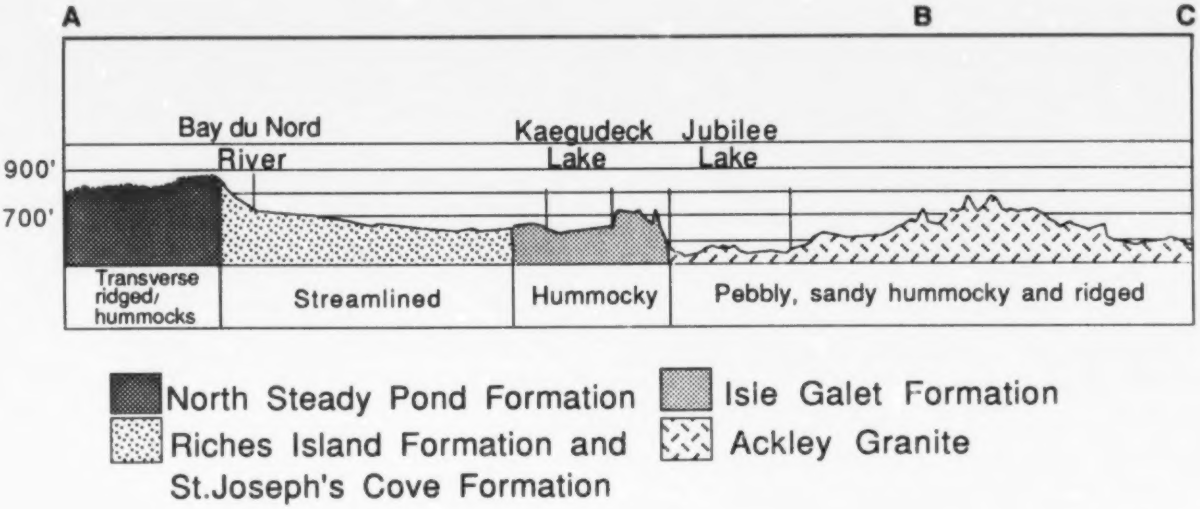

A
B
C
900'
700'
Bay du Nord River
Kaegudeck Lake
Jubilee Lake
Transverse ridged/ hummocks
Streamlined
Hummocky
Pebbly, sandy hummocky and ridged
North Steady Pond Formation
Riches Island Formation and St.Joseph's Cove Formation
Isle Galet Formation
Ackley Granite

Figure 4. *Generalized topographic profile from northwest (A) to southeast (B) across the map area (Figure 2) showing major underlying rock types. The profile continues (B-C) into the Hungry Grove Pond map area (1M/14) south of the Mount Sylvester map area.*

Plate 2. *Rogen moraine surrounded by bog in the northwestern part of the map area.*

100-m wide at their crest and are estimated to be 10- to 15-m high (measurement not possible because they are surrounded by bog that submerges their bases); 2) crescentic ridges that are 50- to 200-m long, 20- to 50-m wide at their crest and about the same height as the Rogen moraine; and 3) an elongate, irregular, discontinuous ridge about the same height as ridges 1 and 2 and 25- to 100-m wide, which can be traced for about 6 km more or less transverse to ice-flow direction. This feature occurs about 2 km north of Conne River Pond (locality 1 on Figure 3) and extends eastward. Several 3- to 5-m exposures within these features near the Bay D'Espoir highway have about 1 m of low-compaction diamicton containing less fines (silt and clay) than underlying till.

Interpretation of these features is constrained by a lack of exposure and extensive bog cover in intervening areas. However, morphologically similar features are reasonably well documented in the literature, so that an airphoto interpretation augmented with a limited number of hand-dug pits (1 m deep) is used here for a preliminary genetic interpretation. The crescentic ridges and Rogen moraine were likely formed subglacially and transverse to ice flow (Lundqvist, 1969; Aario, 1977; Shaw, 1979). This is supported by the regional ice-flow direction, which was tranverse to the ridges. The long discontinuous ridge (number 3 above) appears to be part of a feature that formed along a particular transverse feature within or along the margin of the glacier. Its close proximity to Rogen- and crescentic-ridges, and the fact that it does not superpose them, suggests that it formed subglacially at the same time as the ridges.

For mineral-exploration purposes, sampling should be confined to the transverse features; hummocky features (discussed below) should be avoided. Also samples should be taken from at least 1 m depth to reduce the chances of sampling englacially transported or lag sediment.

Streamlined Terrain

Terrain predominated by depositional features that are streamlined parallel to the main direction of ice flow is confined mainly to the topographically lower northeast–southwest-trending rocks of the Baie d'Espoir Group. These rocks occur more than 3 km northwest (up-ice-flow direction) from its contact with the Ackley Granite (Figures 2 and 3). Several large streamlined ridges also occur southeast of Shoe Hill. This terrain is relatively flat (local relief of less than 20 m) and consists of subparallel streamlined ridges (an even mix of crag and tail and flute features) 5 to 10 m high. The ridges trend 170° (± 10°) and commonly are partially or completely covered by forest. Crag and tail features consist of a relatively steep-sided, resistant, glacially modified bedrock knob (crag) at the up-ice end with a tapering, gently sloping down-ice tail mainly composed of compact sandy-silty till. No up-ice ramps were observed. Flutes have a similar form but no crag is evident. Areas of hummocky moraine are interspersed with these streamlined features (e.g., northeast of Ontwanic Lake, locality 2 on Figure 3) and all features are surrounded by extensive areas of bog that cover about 60 percent of the topographic depression.

The streamlined features found within this area were formed by subglacial deposition and moulding. This interpretation is based on their geometry, which is well documented in the literature (Boulton, 1975, 1976; Aario, 1977), and the fact that they are parallel to glacially abraded striations found on resistant bedrock units in different parts of the map area. Preliminary pebble-lithology analyses indicate that at least the coarse fraction of the sediment that occurs within these streamlined features is of local origin.

Mineralization is well documented in rocks underlying the southeastern part of the area that is dominated by this terrain (Isle Galet Formation, Kim Lake gold prospect) and just northwest of the map area (scheelite). Drift sampling during mineral-exploration projects should be done within the compact massive till that occurs within 1 m of the surface of ridge tops. Sampling near-surface material (less than 1 m below surface) should be avoided because of the potential problem of sampling material that was transported englacially (or at least high up in the basal debris zone of the glacier), and therefore transported farther than basal material. Similarly, sampling near the base of steep ridge slopes should be done with caution because of potential accumulations of slope-wash sediment.

Hummocky Terrain

Single hummocks and small areas of hummocky terrain composed mainly of diamicton with a silty-sandy matrix occur between, and are superimposed upon, other glacial features throughout the map area. Hummocks are estimated to be between 3- and 10-m high and range from isolated features that are 50 m across to areas that are several square kilometers in area. Extensive areas of hummocky terrain occur northeast of Ontwanic Lake, south of Conne River Pond, north of the east end of Kaegudeck Lake, south of Shoe Hill and within about 3 km northwest of the contact between the Baie d'Espoir Group and the Ackley Granite. Where hummocky terrain occurs in small patches, it is surrounded by bog. On Middle Ridge the hummocky features are generally considerably thinner than the transverse ridge features, but they also have surfaces strewn with cobbles and boulders.

The hummocky features within the map area were likely deposited during glacial retreat after the ridged and streamlined features were formed, and probably from an englacial position by melting out of material carried above the basal debris zone of the glacier. They show no evidence of glacial overriding. The cobbles and boulders that lie on the surface of the hummocky terrain and the ridges were likely deposited from more or less clean ice during the last stages of glacial melting. They could also be part of a surface lag created by subglacial-meltwater escape during this time.

Preliminary analysis of the distribution of pebble lithologies from a small number of sample sites appears to support theoretical predictions that hummocky moraine is composed of material that is farther travelled because it is transported higher in the ice than subglacially deposited material (Boulton, 1970). Mineral-exploration sampling programs should be designed so that as few samples as possible are taken from hummocky terrain. Where sampling is necessary within this terrain, it should be done between hummocks.

Terrain with Pebbly and Sandy Hummocks and Ridges

Areas of hummocky sand and gravel overlie most of the Ackley Granite in the eastern and southern parts of the map area. This terrain is poorly vegetated, characterized by an absence of trees and only sparse shrub and grassy areas. The geomorphology within this area is complex because it includes irregular hummocky ridges parallel to the streamlined terrain along with short straight, irregular and arcuate ridges that span linear depressions between the hummocky ridges. In a few places, hummocky ridges form a reticulate pattern. The surface material (to 1 m depth) is predominantly pebbly, moderately- to well-sorted, moderately compacted, massive sand (till?) with scattered cobbles and boulders. Pebbles and cobbles are predominantly granite (probably Ackley Granite) and are generally subrounded.

Eskers occur east of Kaegudeck Lake and south of Koskaecodde Lake and other short, segmented, esker-like ridges occur in many areas. The sand in the eskers is generally better sorted than in the hummocks in the same area and is mainly grit sized. At one site, probable crescentic percussion marks were observed on some cobbles, supporting an esker interpretation (i.e., deposition from high velocity water). Like the hummocks in this area, esker surfaces are strewn with cobbles and boulders.

It is likely that this pebbly, sandy, hummocky terrain has a polygenetic origin beginning with the formation of streamlined ridges similar to those that predominate to the northwest of this area (streamlined terrain). This interpretation is based primarily on the fact that ridges in both zones are parallel, and were, therefore, likely formed during the same ice advance and, secondarily, on the apparent superposition of hummocks and eskers on these features. Within this sandy hummocky terrain, areas with a reticulate pattern of hummocks and ridges are interpreted to be crevasse-fill structures similar to the pattern of ice cracks on disintegrating modern glaciers (Johnson, 1975). The sandy matrix of the material that comprises this terrain is likely the result of sorting by water, although the supply of fines from the underlying granite was likely minimal. The presence of eskers supports this hypothesis. The modern surface is strewn with grit-sized mineral and rock fragments of granite that are the result of mechanical weathering.

Boulder Field

A small low-relief (less than 10 m) area completely covered with unoriented, subrounded to subangular boulders and cobbles of predominantly (greater than 80 percent) local origin that have no matrix (open-work texture) occurs on islands in the east end of Jubilee Lake. There are no abrasion structures preserved on these clasts and most are subrounded, presumably because the rock (mostly granite) is highly susceptible to weathering. Mapping of this unit required detailed ground control that was not always possible so that it may have been included within the bedrock unit in other parts of the map area. This unit was recognized only in an area that overlyies the Ackley Granite.

The genesis of this unit is somewhat problematic mainly because of a lack of subsurface data. However, a number of significant observations are: 1) most of the clasts are similar to the underlying bedrock (granite); 2) exotic rock types show some evidence of abrasion; and 3) the boulder and cobble field forms a relatively featureless surface that does not have consistent or significant slopes and is not confined to the base of slopes.

Two main conclusions can be drawn from this scant information. First, the boulder field was not deposited directly from glaciers because even along the up-ice contacts very few exotic rocks are present. This is in contrast to the abundance of exotic rocks on all rock types up-ice of the Ackley Granite. Second, the boulder field resembles felsenmeer (Washburn, 1973), that is, it formed by frost wedging (probably active at present) of glaciated bedrock that was overlain by a thin discontinuous cover of till. The fines from the till are likely buried at depth and are volumetrically insignificant. Felsenmeer forms predominantly over the Ackley Granite because of favourable jointing and easy mechanical breakdown (Washburn, 1973).

For the purposes of sampling for drift exploration, this map unit is unlikely to be an effective sampling medium.

Colluvial Fans and Aprons

Mappable areas of colluvial sediment (fans and aprons) occur along the steep slope on the north side of Jubilee Lake and about 0.5 km north of Mount Sylvester (locality 3 on Figure 3). The colluvium, although till-like, is generally clast supported and contains angular cobbles and boulders with a silty-sandy matrix. It is coarser grained, less compact and contains a much higher proportion of angular clasts than most till in the study area. These deposits are derived from gravity processes and continue to accumulate in the modern environment.

For drift-prospecting purposes, anomalies can normally be interpreted to be of local origin from steep slopes above.

Organic Plain

Extensive areas of bog and fen cover over half of the map area. These areas consist of an organic accumulation that is water saturated and generally less than 2 m thick (maximum thickness measured was 3.5 m). Most areas are flat lying with less than 2 m of relief, but along the south side of Middle Ridge the bog and fen is gently inclined to the south so that there is water flow across and through the organic material.

This organic cover not only obscures bedrock but presents problems for drift-exploration sampling. In particular, it is difficult to know what material is being sampled below the organic cover. In general, bog forms in low areas that were formerly ponds that acted as sediment traps before the establishment of vegetation. It is therefore important that subsurface bog samples be taken from at least 1 m beneath the top of the underlying drift. Evaluation of geochemical-drift anomalies should take into consideration the reducing environment within and beneath bogs, which can cause misleading high and low values because of great differences in the mobility of ions within this environment. Selected sites should be bulk sampled using a backhoe so that this type of problem can be eliminated.

DISCUSSION

The glacial-landform complexes in the map area can be subdivided into three zones based on landforms that are streamlined parallel to, or formed transverse to glacier flow. They form an apparently transitional lateral sequence arranged along the direction of ice flow. Each zone roughly coincides with underlying bedrock type. The transverse and streamlined zones were overlain subsequently by a discontinuous cover of hummocky and reticulate-ridged sediment. The resulting landscape is divided into three zones based on geomorphology and sediment type. From northwest to southeast they are: 1) terrain dominated by transverse ridges that are composed of silty-sandy diamicton, 2) terrain dominated by streamlined ridges composed of silty-sandy diamicton, and 3) terrain dominated by pebbly, sandy hummocks and ridges that form complex features parallel and transverse to ice flow.

The downglacier-flow transition from transverse features (crescentic ridges and Rogen moraine) to streamlined features (flutes, crag and tails) that formed parallel to ice flow is interpreted to be the result of subglacial processes (Lundqvist, 1969; Boulton, 1976; Aario, 1977). Throughout the map area, hummocky features superimpose streamlined and transverse features. This suggests that sediment comprising the hummocks was deposited from higher in the ice, probably after the ice had stopped flowing, since there is no glacial-flow disturbance of hummocks. The concentration of hummocky terrain composed of silty-sandy diamicton just north of the northern contact of the Ackley Granite has two possible origins. It could be the result of subglacial accumulation (infilling) in the topographic depression that contains Kaegudeck Lake. A local thickening of the basal debris-rich zone of the glacier within this depression would result in a much thicker sediment accumulation, which because of its ice content, would form hummocks during meltout. Alternatively, it could be an accumulation that formed when the glacier margin was stopped in this area during retreat. The abrupt change to hummocky and ridged pebbly sand down-ice of the Ackley Granite is in part related to the material available for excavation by the advancing glacier (disintegrated granite), but it could also have been the site of a stagnant ice margin. This is inferred from the reticulate ridge and hummocky geomorphology and the obvious abundance of flowing water (eskers and esker-like ridges) that characterize such an environment.

Implications for Drift Exploration

Despite the complexity of the landscape and its genesis within the map area, there are some clear implications for drift exploration. To begin, the ice-flow history of the sediment and clasts that form the landscape is simple. One ice-flow direction (170° ± 10°) dominated to the point of destroying any evidence, if any, for earlier flow directions. Therefore the interpretation of drift anomalies is unlikely to be complicated by complex glacial dispersion. A second point is that throughout the area there are subglacially formed landforms (crescentic ridges, Rogen moraine, flutes, crag and tails) that contain compact subglacial till that is optimal for sampling because the sediment is likely to be of relatively local origin. Third, features within hummocky terrain are less likely to contain material that is locally derived and therefore should not be sampled. Finally, the surficial landscape exposed above bog cover is strewn with boulders and cobbles that are interpreted to have been deposited in the late stages of hummocky terrain deposition. Furthermore, deeper exposures (greater than 2 m) show that the near-surface sediment (less than 1 m deep) is less compact, contains less fines and was probably deposited in the late stages of hummock formation. Therefore it should not be sampled.

In much of the area, bog cover is a major problem. Work indicates that the bogs are generally less than 1.5 m deep, and therefore samples can be obtained from beneath them. Routine subsurface bog sampling by hand auger should be supplemented using portable backhoe pits to ensure that the material being sampled is till, and to provide some bulk samples for control purposes.

ACKNOWLEDGMENTS

This study would not have been possible without the friendly and enthusiastic technical and logistical help of Lawson Dickson. Lloyd St. Croix carried out many of the logistical field tasks as well as office support. Mel Reasoner and Rob MacDonald provided capable and affable field assistance. Barry McHale of Tillicum Resources Limited gave us the opportunity to examine backhoe pits in the Little River area about 15 km southwest of the map area. Gerard Hartery of Universal Helicopters Limited supplied us with safe and friendly service. Emmanuel Goosney provided us with excellent backhoe exposures even in boggy terrain. Thank you also to Barry Wheaton for his entertainment and comradery.

REFERENCES

Aario, Risto
1977: Classification and terminology of morainal landforms in Finland. Boreas, Volume 6, pages 87-100.

Boulton, G.S.
1970: On the origin and transport of englacial debris in Svalbard glaciers. Journal of Glaciology, Volume 9, pages 213-229.

1975: Processes and patterns of subglacial sedimentation. *In* Ice ages: ancient and modern. *Edited by* A.E. Wright and F. Mosely. Seel House Press, Liverpool, pages 7-42.

1976: The origin of glacially-fluted surfaces—observations and theory. Journal of Glaciology, Volume 17, pages 87-309.

Dickson, W.L.
1983: Geology, geochemistry and mineral potential of the Ackley Granite and parts of the North West Brook and Eastern Meelpaeg Complexes, southeast Newfoundland, (Parts of map areas 1M/10,11,14,15,16; 2D/1,2,3 and 7). Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-6, 129 pages.

1986: Mount Sylvester (2D/3), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File map 86-66.

1987: Geology of the Mount Sylvester (2D/3) map area, central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 283-296.

Jenness, S.E.
1960: Late Pleistocene glaciation of eastern Newfoundland. Geological Society of America, Bulletin, Volume 71, pages 161-180.

Johnson, P.G.
1975: Recent crevasse fillings at the terminus of the Donjek Glacier, St. Elias Mountains, Yukon Territory. Quaestiones Geographicae, Volume 2, pages 53-59.

Lundqvist, J.
1969: Problems of the so-called Rogen moraine. Sveriges Geologiska Undersökning, Series C, Number 648, pages 1-32.

McHale, K.B.
1985: Report of exploration activities, Kim Lake area, project 403 (for Westfield Minerals). Tillicum Resources Limited. Unpublished report, 94 pages. [2D/3 (152)]

McHale, K.B. and McKillen, T.N.
1986: The Little River Project, south central Newfoundland. 1986 Exploration Activities. Westfield Minerals Limited. Unpublished report, 18 pages. [Nfld (1502)]

Shaw, John.
1979: Genesis of the Sveg tills and Rogen moraines of central Sweden: a model of basal melt out. Boreas, Volume 8, pages 409-426.

Washburn, A.L.
1973: Periglacial processes and environments. Fletcher and Sons Limited, Norwich, England, 320 pages.

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 367-372

AGGREGATE POTENTIAL OF BEDROCK ON THE AVALON PENINSULA

Dan Bragg and Glenn Norman[1]
Quaternary Geology Section

ABSTRACT

Aggregates (sand, gravel, crushed stone) are nonrenewable mineral commodities that are being continuously depleted by the rapid increase in demand by the construction industry for aggregate use in cement, concrete, asphalt, railway ballast, armour stone, gravel roads and as fill material.

Due to the scarcity of granular aggregate deposits on the Avalon Peninsula, a reconnaissance study of bedrock aggregate potential for industrial use was initiated in 1985 and completed in 1987. The study involved investigation of all quarries and roadcuts; 537 samples were collected during the two years of the project for geotechnical analyses.

INTRODUCTION

During the 1985 and 1987 field seasons, an evaluation of bedrock aggregate potential on the Avalon Peninsula in eastern Newfoundland was undertaken by an examination of bedrock quarries and road-cuts. This assessment was conducted to determine the quality and quantity of bedrock aggregate for industrial uses, and to eliminate the use of poor-quality rock for aggregate purposes.

The field area covers twenty-two, 1:50,000 map sheets (Figure 1), therefore only road traverses were carried out because of time and manpower limitations.

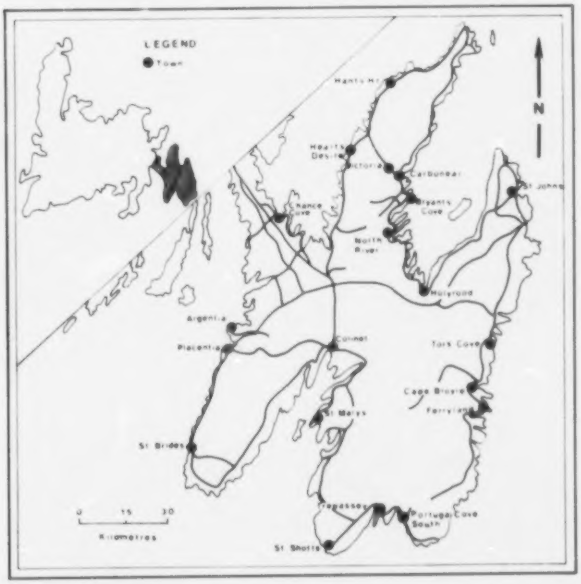


Figure 1. *Location of study area.*

Field Work

Field work consisted of road traverses along all numbered highways and all side roads, and the examination of all rock quarries and roadcuts in the area.

Field investigations at each quarry or site consisted of rock identification, representative sampling, determining (where possible) land ownership and present use, recording overburden type and thickness and describing any geological feature that may be present.

Rock Identification

Rocks were identified according to their genetic origin as either sedimentary (which result from deposition of sediment at the earth's surface by water, wind, ice, or natural chemical processes), igneous (rocks that solidify from molton rock, on or in, the earth's crust), and metamorphic (rocks that have been changed or deformed by high temperature and pressure within the earth's crust). Identification was usually made on site with the aid of a hand lens, but a later, more detailed examination using a petrographic microscope was carried out.

Representative Sampling

At least one representative sample (1 kg) was collected from each quarry or site. However, 2 to 5 samples were commonly taken if the quarry or site were large (greater than 300 m by 300 m), if there were a number of different rock types present, if the degree of weathering varied, or if veining and alteration zones were observed. Much larger samples (about 50 kg) were taken at random for more extensive laboratory analyses.

---

[1] Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland, A1B 3X5

Ownership and Use

The ownership of each quarry, whether operated by the Provincial Government (Department of Transportation) or privately owned, was recorded where possible. Most rock quarries (80 percent) are currently controlled by the Department of Transportation, although a significant number of these (15 to 20 percent) are depleted of reserves. Most of the quarries (greater than 95 percent) were opened to supply materials for use in road construction and the remainder are used in the production of ready-mix concrete.

Overburden Type and Thickness

The main type of overburden observed in the area was a thin (less then 1 m) veneer of till (observed at 70 percent of sites), however, locally, thicknesses range from 0.8 m to 3 m. Sites with no overburden (10 percent of the sites) are completely barren; other sites (20 percent) are thinly vegetated with shrubs and trees.

Geological Features

The main geological features or structures that were considered during the field investigation include faults (Plate 1), fractures (Plate 2), joints (Plate 3), dykes (Plate 4) and cleavage (Plate 5). These affect the breakage pattern of the bedrock and the cost of quarrying, by determining the amounts of explosives required and the amount of waste product, such as excessively oversized or undersized blast material. Microfractures from thin section investigation were also recorded when observed because they affect the compressive strength of the rock.

Other attributes are:

1) grain size—generally, the finer the grain size the harder the rock;

Plate 1. *Faulting in green and red shales in the Conception Group near Bay Roberts.*

Plate 2. *Fracturing in sandstone and siltstone of the Signal Hill Group near St. John's.*

Plate 3. *Sheet jointing in granite of the Swift Current Granite near Swift Current.*

2) bedding structures—important because rocks tend to break more easily along bedding planes and laminae;

3) flow structures—in igneous rocks these tend to be planes of weakness;

4) mineral alignment—common in metamorphic rocks, these tend to be planes of weakness and thus important with regard to excessive rock breakage when blasting,

Plate 4. *Mafic dykes (dark colour) in granite near Swift Current.*

Plate 5. *Schistosity showing cleavages in mica schist near Trans-Canada Highway in Whitbourne area.*

crushing and during the blending of the crushed stone with cement or asphalt binders;

5) mineralization, veining and alteration zones were also noted becausing of their deleterious effect; and

6) weathering–the degree of weathering (fresh, slight, moderate and high).

GENERAL GEOLOGY

The western part of the Avalon Peninsula consists generally of Precambrian sedimentary rocks (siltstones, sandstones, graywackes, shales and conglomerates) of the Musgravetown (Hayes, 1948) and Connecting Point groups (Hayes, 1948). Felsic to mafic volcanic rocks of the Bull Arm Formation (McCartney, 1958) and Harbour Main Group (Rose, 1952) are also present. Usually the shale is locally altered, but any of the above rock types may be altered or deformed.

The eastern section of the Avalon Peninsula consists mainly of Precambrian sedimentary rocks (siltstones, sandstones, arkose, shales, argillites and conglomerates) of the Conception, St. John's and Signal Hill groups (Williams and King, 1979) with sporadic occurrences of volcanic rocks from the Harbour Main Group and granitic rocks of the Holyrood Plutonic Series. These rock types, like their western Avalon counterparts, are fairly fresh and unaltered except locally.

ROCK TYPES AND USES

Rock types in any given area that are being considered for aggregate use should be rated on the basis of the amount of deleterious substances and their petrographic number.

Deleterious substances are materials in the rock that are capable of producing adverse effects (such as chemical reactions with other minerals) that cause deterioration of the rock or the cement binder used in concrete or asphalt. Some common deleterious substances are: clays, organic matter, mica, iron- and manganese-oxide staining, and cherty or fine grained siliceous material. Alteration zones, incrustations, and weathering are also factors that are considered deleterious to the rock.

The petrographic number is the sum of the products of the petrographic factors. The petrographic factors 1, 3, 6 and 10 (CSA Standard A2312) (Table 1 of this report) and a revised version (Table 2; Bragg, 1986) are numbers given to different rock types which indicate the quality of the rock. A petrographic factor of 1 usually means good or best quality and 10 means worst or deleterious; thus the lower the petrographic number the more superior the rock quality, which is expressed in the range of 100 to 1000 i.e., a clean, hard, unweathered granite would normally have a petrographic number of 100, whereas a friable, soft shale would be 1000. The quality is usually affected by the presence or absence of deleterious substances and/or weathering (Table 3).

Sedimentary rocks, because of their variability, may or may not be suitable for aggregate use. The sedimentary rocks on the Avalon Peninsula that are suitable for aggregate use are sandstone, siltstone, arkose and graywacke, providing they are hard, dense, fresh and free of deleterious substances. Sandstone, siltstone, arkose and greywacke have a

Table 1. Rock type and petrographic factors

Rock Type	Classification	Factor
Carbonates (hard)	good	1
Carbonates (sandy, hard)	good	1
Sandstone (hard)	good	1
Gneiss (hard)	good	1
Quartzite (coarse grained)	good	1
Greywacke–arkose	good	1
Volcanic (slightly weathered)	good	1
Granite–diorite	good	1
Trap	good	1
Magnetite	good	1
Pyrite (disseminated in trap)	good	1
Iron-bearing quartzite	good	1
Sedimentary conglomerate (hard)	good	1
Carbonates (slightly weathered)	fair	3
Carbonates (sandy, medium hard)	fair	3
Sandstone (medium hard)	fair	3
Crystalline carbonates (hard)	fair	3
Crystalline carbonates (slightly weathered)	fair	3
Gneiss (soft)	fair	3
Chert and cherty carbonates	fair	3
Granite (friable)	fair	3
Volcanic (soft)	fair	3
Pyrite (pure)	fair	3
Flints and jaspers	fair	3
Carbonates (soft, slightly shaly)	poor	6
Carbonates (soft, sandy)	poor	6
Carbonates (deeply weathered)	poor	6
Carbonates (shaly clay)	poor	6
Carbonates (ochreous)	poor	6
Chert and cherty carbonates (weathered)	poor	6
Sandstone (soft, friable)	poor	6
Quartzite (fine grained)	poor	6
Crystalline carbonates (very soft, porous)	poor	6
Gneiss (friable)	poor	6
Granite (friable)	poor	6
Encrustations	poor	6
Cementations	poor	6
Schist (soft)	poor	6
Ochre	deleterious	10
Shale	deleterious	10
Clay	deleterious	10
Decomposed volcanics	deleterious	10
Slates	deleterious	10
Talc-gypsum	deleterious	10
Iron formations (very soft)	deleterious	10
Sibley formation	deleterious	10

petrographic factor range of 1 to 6 with a usual factor of 1 when fresh and hard. These rock types may all be used as crushed-stone aggregate for roads, concrete, breakwaters, asphalt, canals, dams, retaining wall construction and railway and road ballast. The sedimentary rocks on the Avalon Peninsula that are usually unsuitable for aggregate use are shale, conglomerate and argillite. Shale, which has a high petrographic factor of 10, because of its softness, friability and mineral content, is not usually used as an aggregate. However, it may be used extensively as a raw material in Portland cement and in some lightweight aggregates. It may also be used as a fill or ballast for road construction.

Table 2. Revised petrographic factors for some rock types

Rock Type	Petrographic Factor Range	Usual Factor
1. Sandstone	1-6	1
2. Shale	10	10
3. Mudstone	3-6	6
4. Siltstone	1-6	1
5. Conglomerate	1-10	6
6. Arkose	1-6	1
7. Argillite	3-6	6
8. Graywacke	1-6	1
9. Chert	1-3	1
10. Limestone	1-6	1
11. Dolomite	1-6	1
12. Quartzite	1-6	1
13. Granite	1-6	1
14. Gabbro	1-6	1
15. Diorite	1-6	1
16. Granite-diorite series	1-6	1
17. Felsic volcanics	1-6	1
18. Mafic volcanics	1-6	1
19. Intermediate volcanics	1-6	1
20. Felsic-mafic volcanics	1-6	1
21. Pyroclastics	3-6	3
22. Metavolcanics	3-6	3
23. Gneiss	1-6	3
24. Schist	3-10	6
25. Phyllite	6-10	6
26. Marble	1-6	1
27. Slate	10	10
28. Amphibolite	6-10	6
29. Ultramafic	6-10	6
30. Metasediments	1-6	3
31. Iron formation	6-10	6
32. Drift deposits	Any or all of the above	Any or all of the above

Table 3. Affect of weathering on petrographic factors

Petrographic Factor	Weathering Grade	Final Petrographic Factors
1	1, 2	1,2
	3	3,4,5
	4, 5	6,7,8,9
	6	10
3	1, 2	3,4,5
	3, 4	6,7,8,9
	5, 6	10
6	1, 2	6,7,8,9
	3, 4, 5, 6	10
10	1, 2, 3, 4, 5, 6	10

Conglomerate has a high petrographic factor range of 1 to 10 and a usual factor of 6 when fresh. It is not used normally as an aggregate, because of its weak internal cement, which may break down during handling of the rock. However, some cemented homogeneous conglomerates (i.e., those composed of mainly volcanic or granitic particles) may be used as armour stone for breakwater construction. Argillite has a petrographic range of 3 to 6 and a usual factor of 6 when fresh. Although it is not normally used for aggregate it may be used for road fill and as a raw material for the ceramic industry, brick manufacturing and refractory materials.

Igneous rocks of the Avalon Peninsula have been subdivided on the basis of coarseness. Medium- to coarse-grained rocks are generally plutonic (intrusive), and the fine grained rocks are volcanic (extrusive).

In this report, intrusive rocks are classified as granite, diorite, monzonite, gabbro and syenite and extrusive rocks are classified as rhyolite, andesite, basalt, dacite and pyroclastics (tuffs and breccias). The above igneous rocks have petrographic factors ranging from 1 to 6 and a usual factor of 1 when fresh.

The medium- to coarse-grained intrusive rocks mentioned above are all excellent sources of aggregate material, and can be used for industrial and architectural purposes. The industrial uses include crushed stone for road construction, dams, bridges, pavement, retaining walls, railway ballast and foundation blocks. Architectural uses include dimension stone for ornamental and structural use in monumental structures, private, residential, commercial and institutional building complexes.

Fine grained extrusive volcanic rocks are usually excellent aggregate materials, but care should be taken when they are used in concrete. Highly siliceous rocks may react chemically with the high-alkali cements, resulting in progressive deterioration of the material. The volcanic rocks that may react are rhyolites, dacites, and andesites. The extrusive rocks may be used for the same purposes as their intrusive counterparts.

Metamorphic rocks may be suitable or unsuitable for aggregate use depending on their mineralogical character. The only metamorphic rock noted on the Avalon Peninsula is slate. This rock is usually unsuitable for aggregate use because of its mineral content, distinct cleavage and softness. It is used extensively, however, as dimension stone for a number of purposes such as roofing and floor tiles. The petrographic factor of slate is 10.

LABORATORY INVESTIGATION

Petrographic examination (ASTM method C-295.65, 1973) and C.S.A. Standard A23.2 (1973)) is being carried out on all hand specimens and thin sections. Petrographic examination involves determining the quality of the rock sample by identification of microstructures (fractures in the crystals) and altered minerals due to weathering or metamorphic factors.

The Magnesium Sulfate Soundness test ASTM (88-78), which is used to indicate the durability of a aggregate, was also carried out on random samples. This test involves placing a quantity of the sample (300 grams) in a wire mesh basket and submerging it in a solution of magnesium sulfate for 16 to 18 hours. Then the sample is dried for 8 hours at 230°F (110°C). This process is repeated a number of times and the sample sieved again. Any loss of the aggregate or crushed stone through the sieve is calculated as a percentage of loss.

The Los Angeles Abrasion Test (ASTM-C131-69) for small-size, coarse aggregate was also conducted on randomly selected samples. This test consists of placing a 5-kg sample in a horizontal steel drum, containing a number of steel balls. The drum is rotated for 15 minutes at 33 revolutions per minute. After the test, the sample is sieved and the percentage of loss is calculated.

SUMMARY

A total of 517 sites were visited and 537 samples collected during the two field seasons of the project. Thin sections were made of all the samples and petrographic analyses is presently underway.

A more comprehensive report is scheduled for publication in the spring of 1988, and will give detailed descriptions of each site and sample. This will eliminate certain sites for aggregate use and promote others. The report will provide a data base for the exploitation of bedrock for aggregate and architectural purposes on the Avalon Peninsula.

REFERENCES

American Society for Testing and Materials
1973: Annual ASTM standards, C88-73, C295-73.

Bragg, D.J.
1986: Reconnaissance study of bedrock aggregate for offshore and industrial use. *In* Current Research. Newfoundland Department of Mines, Mineral Development Division, Report 86-1, pages 297-301.

Canadian Standards Association
1973: Canadian Standards Association Standards, A23.2.30.

Hayes, A.O.
1948: Geology of the area between Bonavista and Trinity Bays, eastern Newfoundland. Geological Survey of Newfoundland, Bulletin 32, Part 1, 49 pages.

McCartney, W.D.
1958: Geology of Sunnyside map area, Newfoundland. Geological Survey of Canada, Report and Map 18-1958, 21 pages.

Rose, E.R.
1952: Torbay map area, Newfoundland. Geological Survey of Canada, Memoir 265, 58 pages.

Williams, H. and King, A.F.
1979: Trepassey map area, Newfoundland. Geological Survey of Canada, Memoir 389, 24 pages.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 373-377

DETAILED AGGREGATE RESOURCE ASSESSMENTS–INSULAR NEWFOUNDLAND

F.T. Kirby
Quaternary Geology Section

ABSTRACT

This report summarizes results of the 1987 detailed assessment of the aggregate potential of: (1) the Robert's Arm municipal planning area, (2) the Roddickton, Bide Arm and Englee municipal planning areas and (3) the St. John's Peninsula and Conception Bay North region.

The study has verified that the Robert's Arm, Roddickton, Bide Arm and Englee study areas lack any substantial reserves of high quality surficial-aggregate materials.

In the St. John's Peninsula and Conception Bay North areas, field work involved the sampling of bedrock to assess its potential as an aggregate source along with a hammer seismic survey at preselected sites throughout the St. John's Urban Region. The objective of the latter study is to evaluate the potential of the hammer seismic instrument in determining overburden thickness, so that aggregate reserves can be estimated in areas of high aggregate potential. The results of this survey are not yet available.

INTRODUCTION

A program of aggregate-resource assessment was initiated in 1982 to evaluate in detail the aggregate-resource potential of selected areas of the province. The focus of the program has been on areas where municipal planning is ongoing. The existing regional aggregate-resource data (Kirby *et al.*, 1983) is of invaluable assistance in defining conflict areas, but was not adequate in providing detailed information on the aggregate resources necessary to resolve these conflicts. To date, detailed aggregate surveys have been completed in 44 municipal planning areas and the results forwarded to the Department of Municipal Affairs for inclusion in appropriate municipal plans. In most cases, the recommendations have been adopted or modified. For unresolved issues, discussions are underway.

In 1987, the author conducted field work in the Robert's Arm, Roddickton, Bide Arm and Englee municipal planning areas, and in the St. John's Peninsula and Conception Bay North region (Figure 1).

Field Program

Areas were preselected for detailed aggregate analysis following a review of all available aggregate resource and surficial data. The first phase of field work involved vehicular traverses along all passable roads to update data on previously sampled and unsampled surficial deposits (Kirby *et al.*, 1983). Foot traverses were conducted in the preselected target areas and other areas of potential quarry development within the identified planning area.

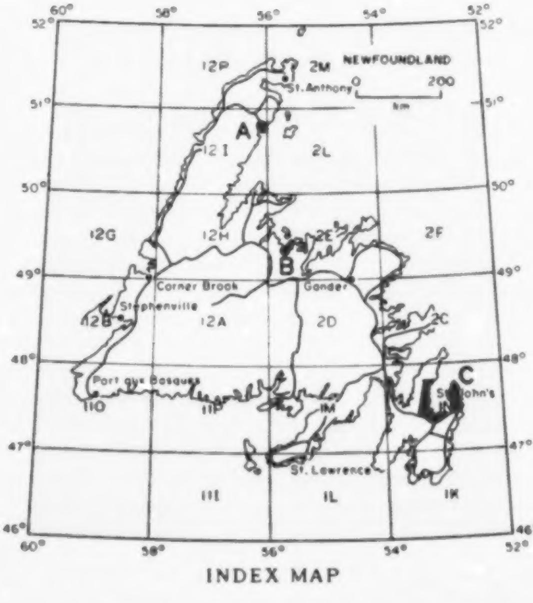
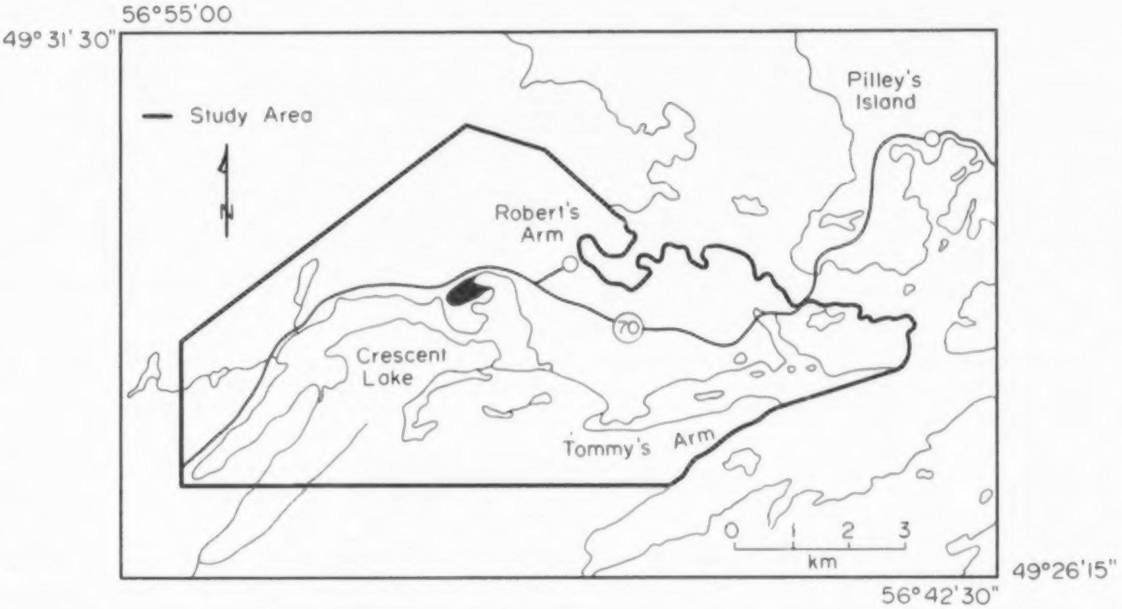


Figure 1. *Location of study areas: (A) Roddickton–Englee–Bide Arm area; (B) Robert's Arm area; (C) St. John's Peninsula–Conception Bay North.*

In the St. John's Peninsula area, hammer seismic work using a Huntec FS-3, Portable Facsimile seismograph was conducted to determine the thickness of overburden in



● *Proposed aggregate-reserve areas*

Figure 2. *Aggregate-reserve areas within the Robert's Arm Municipal Planning Area.*

aggregate-resource areas previously identified by the Detailed Aggregate Resources Assessment Program in 1983 (Newfoundland Department of Municipal Affairs (1986).

Data Analysis and Computer Storage

Seventy-eight aggregate samples were collected during the 1987 field program. Samples of unconsolidated aggregates containing plus 8 mm size material were field sieved, and a split of the minus 8 mm fraction was retained for laboratory sieve analysis (Kirby *et al.*, 1983). A split (about 100 pebbles) of the 16 to 31.6 mm pebble fraction was retained for field lithological and petrographic analyses.

Prior to 1986, all aggregate-resource data were incorporated into the Scientific Information Retrieval (S.I.R.) computer system. In 1986, the Mineral Development Division acquired its own minicomputer (HP9000/560), which will enable the in-house storage and computing of all aggregate resource data.

STUDY RESULTS

Robert's Arm (2E/5 and 2E/12)

The surficial geology of the Robert's Arm Municipal Planning area is characterized by rock outcrop and a thin veneer of till and/or frost-shattered rock overlying bedrock. The only sand and gravel deposit in the area is confined to a small glaciofluvial terrace at Crescent Lake (Figure 2). This deposit is composed of 3 to 5 m exposures of stratified sandy gravel and sand. Being the only local source of gravel, the deposit has been heavily exploited. Approximately 70 percent of the previously existing resource has been extracted. Up to 50 percent of the remaining deposit is located within a municipal camping park, which is not presently in use. Partical size and petrographic analyses of samples collected from this deposit give an average grain size distribution of 30 percent gravel, 69 percent sand and 1 percent silt–clay and a petrographic number (Bragg, 1986) ranging between 271 and 353.

The relatively high petrographic number is the result of weathering of the pebble content of the gravels, which makes this deposit unsuitable for asphaltic pavement or concrete. However, local residents have utilized the material for concrete in house foundations and walkways. The sand content of the gravels is suitable for blending-sand for asphaltic pavement and concrete, and is also used for road ice control during the winter months.

Till deposits in the area are thin (usually less than 1 m) and are confined to shallow veneers over bedrock. These deposits are small and of insufficient quality for high grade aggregate use. Silt–clay contents range from 6 to greater than 15 percent.

The bedrock geology (Dean, 1977) of the Robert's Arm planning area mainly consists of basalts interbedded with cherty sediments. Where fresh or slightly weathered, this rock type is excellent for most high grade aggregate uses. However, the suitability decreases with an increase in the degree of weathering and the presence of deleterious substances such as clay minerals (Bragg, 1986). Generally, the cherty sediments are suitable as a source of high grade aggregate, but if used in cement, alkali reactivity with the cement paste may occur.

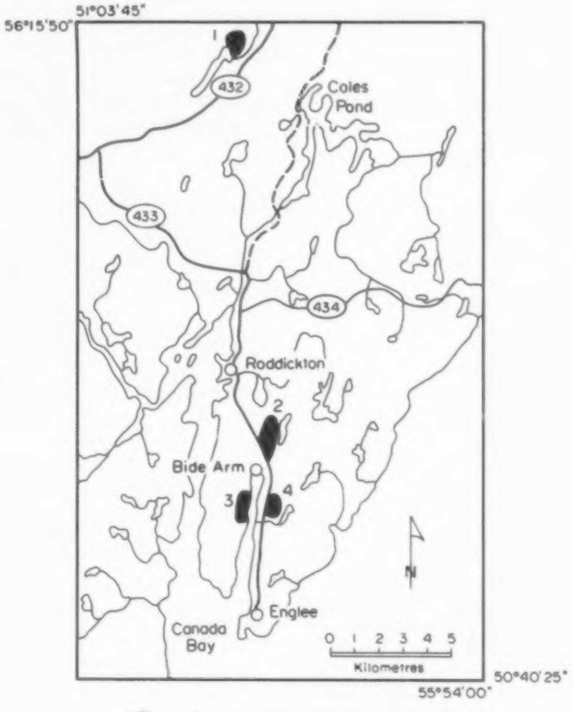
Roddickton–Englee–Bide Arm (12I/9, 12I/16, 12P/1)

The surficial geology of these areas is characterized by thin veneers (less than 2 m) of marine sediments over bedrock. Generally, these deposits are unsorted, but along river valleys (below 75 m above sea level), some of these deposits have undergone varying degrees of washing and sorting. Three glaciomarine deposits with aggregate potential were identified during the survey (Figure 3). The highest potential aggregate source is a terrace deposit located at the northeast end of Scammels Pond (Deposit 1, Figure 3). This deposit is composed of 1 to 5 m of stratified, shelly sand and sandy gravel over bedrock. The deposit is the major source of sand and gravel for concrete and winter sand for ice control for the whole region and therefore has been heavily exploited. The average grain-size distribution for samples collected from this deposit is 59 percent gravel, 39 percent sand and 1 percent silt–clay. The petrographic number ranges from 352 to 372. The high petrographic number of the pebble content of the gravel is the result of the presence of moderately weathered sandstone and badly weathered undefinable lithologies. This high petrographic number precludes the use of these gravels as a source of coarse aggregate in asphaltic pavement or concrete, but the sand content is suitable for blending purposes. The other two deposits identified (Deposits 2 and 3) are located near Bide Arm, and are more massive deposits with a higher silt–clay content (Table 1). The average grain size distribution for samples collected from these deposits is 70 percent gravel, 27 percent sand and 3 percent silt–clay. The petrographic number ranges from 207 to 276. The relatively high petrographic numbers of the pebble content of the gravel is mainly the result of the presence of small percentages of highly weathered undefinable lithologies in the deposit.

Tills in the area are located at elevation generally above 75 m a.s.l. The deposits are usually thin veneers over bedrock or confined to isolated hummocks and ridges. Deposits are usually silty and contain large angular boulders. The average grain-size distribution of till samples collected in this area was 46 percent gravel, 33 percent sand and 21 percent silt–clay. The high silt content and poor petrographic characteristics (petrographic numbers range between 212 and 446) of the samples would make these deposits only suitable as a source of fill.

The writer observed stratified silty sand and gravel with silt lenses at the base of Deposit 2. The high silt content makes this deposit unsuitable for high grade aggregate uses.

The bedrock geology of the study area consists mainly of carbonate rocks of the Table Cove, March Point, Petit Jardin, Catoche, Boat Harbour and Watts Bight formations (Knight, 1987). Where fresh, these rocks are excellent as a source of high quality crushed aggregate. However, the quality of the rock is dependent upon the hardness, degree of weathering and the presence of deleterious substances such as cherty or argillaceous beds. Poor quality (Deposit 4, Figure 3) shale is exposed in the area and is only used as a source of fill.



● *Proposed aggregate-reserve areas.*

Figure 3. *Aggregate-reserve areas in the Roddickton–Englee–Bide Arm region.*

Rocks of the Maiden Point Formation are also exposed in the study area and mainly consist of greywacke, slate and conglomerate. Generally, the greywacke is excellent as a source of crushed aggregate, whereas the slate is poor and could only be used as a source of fill. The conglomerates have a quality range of good to poor, depending on its hardness, durability, degree of weathering and deleterious substances present.

St. John's Peninsula–Conception Bay North (1N/6/7/10/11/14/15)

Field work in this area was divided into two segments; these were, hammer seismic profiling and bedrock evaluation for aggregate purposes.

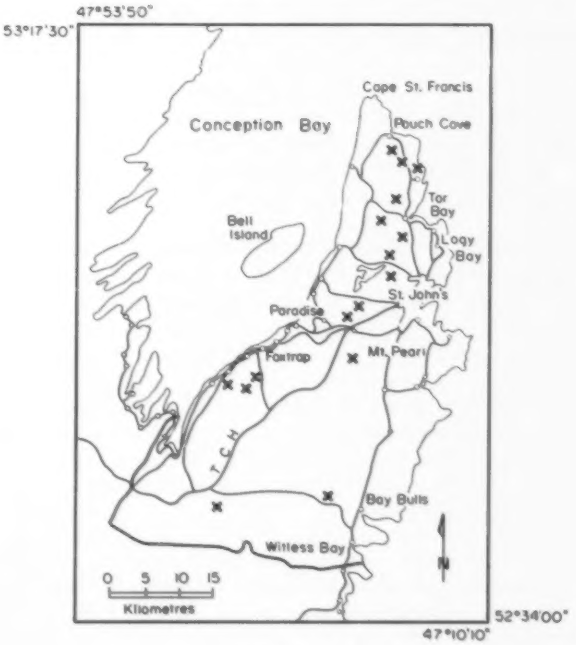
Hammer seismic work was conducted in a number of areas within the St. John's Urban Region (Figure 4). Many of the areas tested are identified as aggregate-resource areas on the St. John's Urban Region Plan and most have already been testpitted by backhoe and sampled (Newfoundland

Table 1. Summary of sieve analysis by area

Deposit	Number of Samples	Average Petro-graphic Number	% Gravel	% Sand	% Silt-Clay	Comments
Robert's Arm	7	312	30	69	1	Predominantly sandy stratified gravel with numerous sand exposures. Average exposure height from quarry faces was 3 m.
Roddickton–Bide Arm–Englee						
1	3	362	59	40	1	1 to 5 m exposures of stratified sandy gravel and sand in a large gravel quarry. The deposit contains numerous shell fragments.
2	3	249	74	23	3	Site is on the side of a rock covered ridge. 1-2 m of unsorted marine sediment overlying 1-2 m of stratified sand and gravel with silt lenses. There is a high percentage of shell fragments in the deposit.
3	2	207	65	32	3	4-6 m of gravelly marine sediment with shell fragments. The deposit does show some stratification.

Department of Municipal Affairs, 1986). The main aim of this project was to evaluate the usefulness of a hammer seismic instrument to determine overburden depth in various terrain and overburden types. The instrument used in this survey was a Huntec FS-3, Portable Facsimile Seismograph (Hammer Seismic). It is hoped that by employing this geophysical method, combined with backhoe testpitting and sampling, a better estimate can be made of the aggregate-resource potential of a given region. A total of seventy hammer seismic profiles were done over a two week period. Analyses of the hammer seismic data have not been completed.

The bedrock-aggregate survey was conducted throughout the region and involved the collection of representative bedrock samples to evaluate their potential as a source of crushed aggregate. This is discussed in Bragg *(this volume)*.



× *Hammer seismic locations*

Figure 4. *Hammer seismic locations within the St. John's Urban Region.*

SUMMARY

A total of 78 aggregate and rock samples were collected and seventy hammer seismic profiles were conducted during the 1987 field season. Laboratory analyses on all aggregate samples have been completed; the hammer seismic data are presently being analyzed.

The work conducted in the Robert's Arm and Roddickton–Bide Arm–Englee areas has shown that these areas lack adequate reserves of high quality surficial-aggregate materials within their municipal boundaries. Bedrock reserves in these areas are generally of high quality and are suitable as a source of crushed aggregate material, but the degree of weathering and presence of deleterious substances would greatly affect the quality of these deposits. The results of these surveys have been forwarded to the Department of Municipal Affairs for inclusion in municipal or other plans for these areas so that the resources identified can be protected from conflicting land uses.

A hammer seismic program was conducted mainly within existing aggregate-resource areas that are identified in the St. John's Urban Region Plan. The main aim of this project was to evaluate the use of this instrument in determining overburden depths in potential aggregate-resource areas. In the Conception Bay–St. John's Peninsula areas, a bedrock sampling program was conducted to determine the potential of each representative rock type as a source of crushed aggregate.

ACKNOWLEDGMENTS

The author wishes to thank Rodrick Mercer and Rob MacDonald for their very capable assistance in the field, and to Christine Blackwood for her prompt results from the laboratory. This report was critically reviewed by Jerry Ricketts, Martin Batterson and David Proudfoot.

REFERENCES

Bragg, D.
1986: Reconnaissance study of bedrock aggregate potential for offshore and industrial use. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 297-301.

This volume: Aggregate potential of bedrock on the Avalon Peninsula for industrial use.

Dean, P.L.
1977: Geology and metallogeny of the Notre Dame Bay area, Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-10, 17 pages.

Kirby, F.T., Ricketts, R.J. and Vanderveer, D.G.
1983: Inventory of aggregate resources in Newfoundland and Labrador, information report and index maps. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-2, 36 pages and Open File maps 83-13, 83-15.

Knight, I.
1987: Geology of the Roddickton (12I/16) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 343-357.

Newfoundland Department of Municipal Affairs
1986: St. John's Urban Region Plan, Draft Proposal, Department of Municipal Affairs, Urban and Rural Planning Division, 81 pages.

*Current Research (1988) Newfoundland Department of Mines,
Mineral Development Division, Report 88-1, pages 379-388*

AGGREGATES FOR EXPORT

M.J. Ricketts
Quaternary Geology Section

ABSTRACT

This report describes an aggregate resource inventory conducted in the St. George's Bay area of western Newfoundland. The aim of the project was to map deposits of granular aggregate material for potential export markets. The area selected for study is adjacent to an ice-free coast, has the necessary infrastructure (wharf facilities and haulage road) and large volumes of granular material.

INTRODUCTION

Initial interest in aggregates for export came about from the results of a study entitled *Study of Markets for Aggregate Materials Accessible from Nova Scotia and New Brunswick*, prepared for Supply and Services Canada (ADI Limited, 1986). Market areas (accessible through the United States Atlantic seaboard) were evaluated from production records for sand and gravel and crushed stone. Maritime aggregate producers have a competitive advantage in production costs for most of the areas investigated, since aggregates are relatively low-cost bulk materials. Transportation can be a very significant proportion of the cost of the product delivered to the end user. A comparison of costs for different modes of transportation is shown in Table 1.

Table 1. Comparative aggregate transportation costs based on an annual volume of 500,000 tonnes per year (ADI Limited, 1986)

Origin	Destination	Truck	Rail	Marine
Saint John	Boston	$45.28	$32.87	$4.00
Mulgrave	Boston	$93.99	$40.44	$4.74

Aggregate resource field work in 1987 was conducted on a 1:50,000 scale in map areas 12B/7 and 12B/8. This is in the vicinity of the Duntar gypsum mine and extends northwest as far as Black Bank Provincial Park in western Newfoundland (Figure 1). This study area was chosen because of large quantities of granular aggregates and because of the shutdown of the gypsum mine in late 1987. With this shutdown a large amount of machinery was left idle, which could be utilized if a large scale aggregate operation begins. Another valuable asset in this area is a loading wharf capable of handling bulk carriers necessary for aggregate export. A 9-km-long haul-road leads from the mine site to the wharf and the road is in close proximity to many of the aggregate zones in the study area.

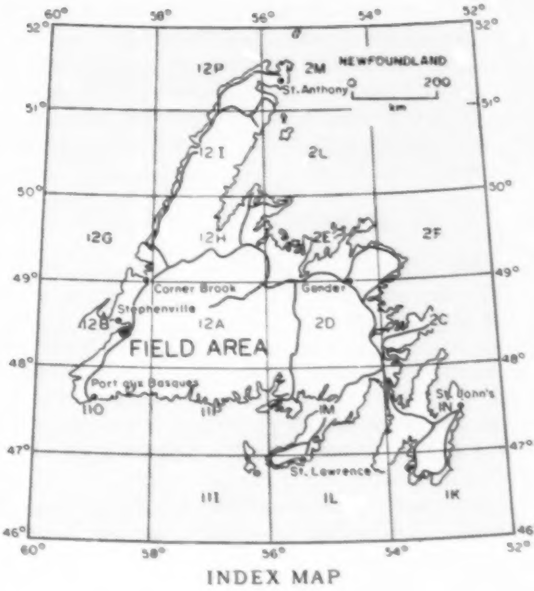


Figure 1. *Location of study area.*

The objective of this project is to locate aggregate deposits and determine their quantity and quality for suitability in the manufacture of portland cement concrete, asphaltic pavements and as highway-base material. These uses account for 80 to 90 percent of sand and gravel utilized in the United States (ADI Limited, 1986).

Deposits sampled are within a 12-km radius of wharf facilities that can be used as a shoreline base for loading raw material. Most deposits are easily accessible by roads leading to this shoreline location. A deposit that can supply 500,000 m^3 annually, for approximately 10 years, is required to make an export venture a profitable one.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989.

FIELD PROGRAM

Coloured aerial photographs at 1:12,500 scale were used as a guide to locate potential resource areas. This procedure provided a framework for field investigation by outlining areas of potential deposits.

Quaternary deposits composed predominantly of glaciofluvial outwash and marine material make up much of the area, particularly along coastal shores and river valleys. Tills are located in areas east of the Trans-Canada Highway and at higher elevations (greater than 26 m above sea level) along the shoreline (Brookes, 1974). Exposed bedrock is scarce.

Field sampling was conducted by vehicle and foot traverses. Where possible, samples were taken from natural exposures such as stream cuts, shorelines and gullied areas. Where natural exposures were not available, samples were collected from hand-dug pits, usually greater than 1 m in depth. Sampling provided material for petrographic and grain size analyses to more accurately determine the boundaries of specific deposits. Field sieve and petrographic analyses were conducted on all samples containing +8 mm size material. A 200- to 500-g split of the sand−silt−clay fraction (finer than 8 mm) was retained for laboratory sieve analyses (Kirby *et al.*, 1983).

LITHOLOGICAL STUDY

Pebble lithology studies were conducted to help determine the geotechnical characteristics of the pebble fraction of aggregates. Following a review of the geological literature related to the study area, and the determination of the percentage of each rock type found in each sample of pebbles, data were collected on silt−clay coating, weathering, staining, sphericity, rounding, fractures, mineralogy and texture of various rock types present in a given pebble sample.

A petrographic number was calculated for each sample following procedures similar to CSA standard A23.2.30 (Canadian Standards Association, 1973). The petrographic number, ranging between 100 and 1000, is derived by taking the sum of the percentage of each pebble type present multiplied by a factor (based on soundness and durability) assigned to that rock type (Bragg, 1986). The lower the number, the better the quality of the aggregate material.

DATA PRESENTATION

Office Program

Particle-size analyses were conducted on 140 samples and lithological analyses on 68 samples. The results of particle-size analyses were used to plot cumulative graphs (Kirby *et al.*, 1983) for each sample. These graphs show percentages of gravel, sand and silt−clay for each sample. Petrographic numbers are also shown on the graphs.

A review of landform classification data and particle analyses was made and results were drafted on 1:12,500 scale maps. These results include zones of sand and gravel, sample numbers and type of samples collected (sand, gravel, silt and till). It should be noted that the boundaries around designated areas (zones) are determined from air photos and field investigations and may not represent the true extent of any deposit that can be used as a source of aggregate.

AGGREGATE ZONES

A brief description is given for each of the 26 aggregate zones (Figure 2 and Table 2) in the map area. This description includes: estimated reserves (listed in cubic meters) for each zone; exposure types from where samples were collected; cumulative thickness of topsoil and iron oxide layers and obstacles that may affect mining (forest growth and residential development); average percentages of gravel, sand and silt−clay; the average dominant particle size for each zone; and a range of petrographic numbers and their average. In zones with high sand concentrations, pebble content was not extensive enough to conduct detailed petrographic analyses on coarse grained material. Gravel clasts greater than approximately 100 mm could not be accurately sieved using available field equipment, therefore a visual estimate of boulder content was made at each sample site.

Zone Description

Zone 1 contains a terrace deposit situated on the west side of the Terra Transport railway track (formerly C.N.R.) between Little Barachois Brook and Black Bank Provincial Park. Forest growth covers much of the area together with scattered farmland and pastureland. A residential area is located in the southern end of the zone. This zone is approximately 1500 m long, 200 m wide, 12 m high and contains an estimated 2,000,000 m³ of material.

Topsoil and iron oxide thicknesses average 0.5 m in this area. Particle-size analyses of ten samples collected from shoreline exposures show that the ten samples average 3 percent gravel, 88 percent sand and 8 percent silt−clay. Particles between 0.125 and 0.5 mm are dominant, forming 50 percent of sieved material. Petrographic analyses were not conducted for this zone due to lack of coarse material (greater than 16 mm).

Zone 2 contains a terrace deposit situated on the north side of Route 461, between Turf Point and Barachois Brook. This zone is predominantly forest covered but has an extensive residential area along Route 461 in the southwest section of the zone. However, there is less extensive development along two roads branching off Route 461. It is approximately 2000 m long, 400 m wide, up to 17 m thick and contains an estimated 10,000,000 m³ of material.

Samples collected came from shoreline exposures (Plate 1) along the north side of the zone and from two quarries near the east end of the zone. Topsoil and iron oxide average 0.5 m thick. Shoreline exposures are predominantly composed of stratified sands, and, in places, are overlain by pebbly gravel up to 0.4 m in thickness. Thicker gravel units (3 to

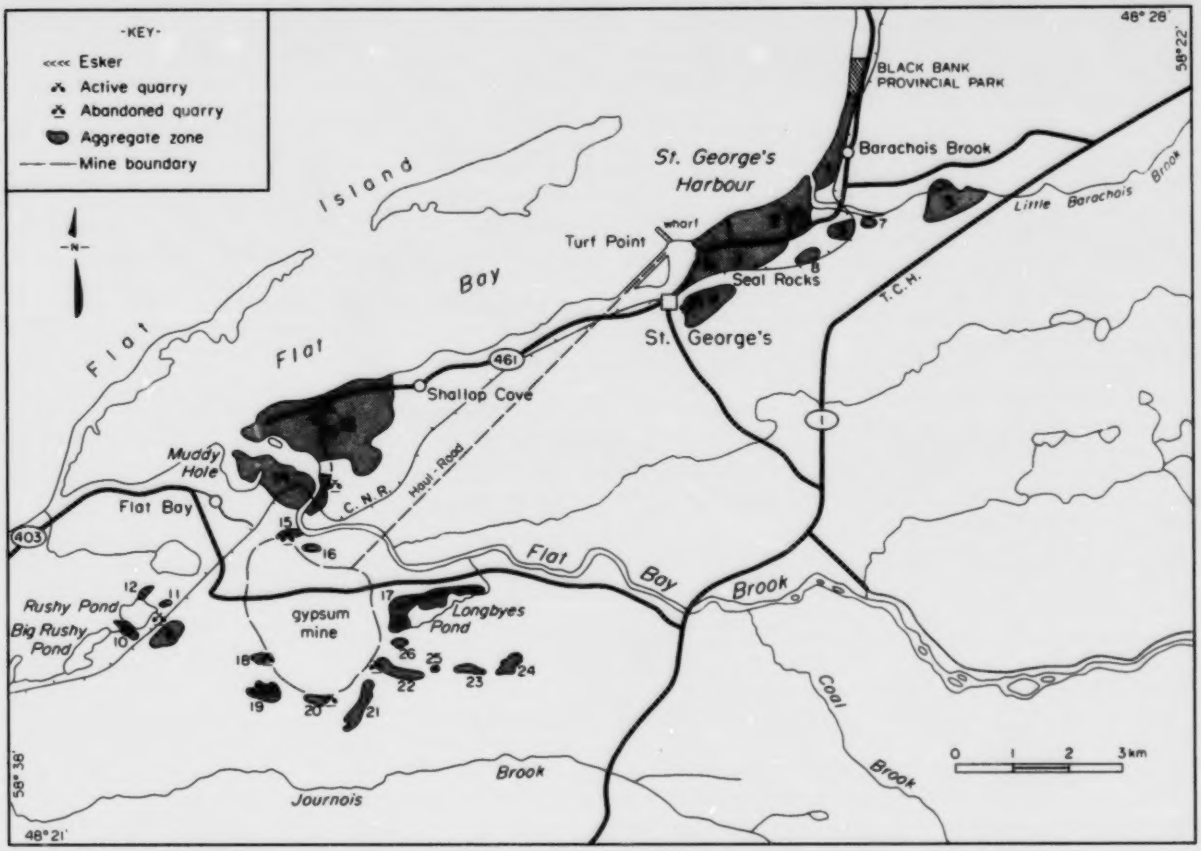

-KEY-
Esker
Active quarry
Abandoned quarry
Aggregate zone
Mine boundary
N
48° 28'
58°22'
58° 38'
48°21'
BLACK BANK PROVINCIAL PARK
Barachois Brook
Little Barachois Brook
St. George's Harbour
Island
Flat Bay
Turf Point
wharf
Seal Rocks
St. George's
T.C.H.
461
1
Shallop Cove
Muddy Hole
Flat Bay
403
C.N.R.
Haul Road
Flat Bay Brook
gypsum mine
Longbyes Pond
Rushy Pond
Big Rushy Pond
Coal Brook
Journois Brook
0 1 2 3km
1
2
3
4
5
6
7
8
9
10
11
12
15
16
17
18
19
20
21
22
23
24
25
26

Figure 2. *Study area showing aggregate zones 1 to 26.*

Plate 1. *Eight-m-high sandy shoreline exposure in Zone 2.*

4 m) were noted at one of the quarry sites, however, these are nearly depleted and sand exposures are now common along most of the quarry face. A layer of compacted, stratified silt–clay sediment was also noted in the shoreline exposure. This silt–clay unit is approximately 200 m long and 6 m thick.

Particle-size analyses of 12 samples collected in Zone 2 (excluding the silt–clay unit) show an average of 7 percent gravel, 85 percent sand and 8 percent silt–clay. The dominant particle size occurs between 0.25 and 0.125 mm, forming 31 percent of sieved material. Particle sizes between 0.25 and 0.5 mm account for another 28 percent. Petrographic numbers determined by analyses of three samples are 107, 110 and 147.

Zone 3 is located south of Zone 2, between Route 461 and the Terra Transport railway track. Aggregate extraction will be affected by a residential area along Route 461, which is most extensive in the east and west sections of the zone. The south and central areas are covered by dense forest and scattered cut-overs. The zone is approximately 1500 m long, 300 m wide and contains an estimated 2,000,000 m^3 of material.

Eight of the ten samples collected in this area came from backhoe pits averaging 3 m in depth; the other two were taken

Table 2. Summary and comparisons of aggregate zones sampled in the St. George's Bay area of western Newfoundland

		Petrographic Analyses			Particle Size Analyses			
Zone	Estimated m³	# of Samples Analyzed	Average	Range	# of Samples Analyzed	% Gravel (+ 5mm)	% Sand (+0.078mm to +5mm)	% Silt−Clay (-0.078mm)
1	2,000,000	0	-		11	3.54	88.22	7.63
2	10,000,000	3	114	107-125	12	7.16	84.95	7.90
3	2,000,000	7	120	102-155	11	26.24	71.51	2.15
4	1,000,000	1	111		6	3.47	92.89	3.61
5	1,280,000	5	116	101-137	8	25.3	73.3	1.3
6	130,000	1	106		1	39.2	60.4	0.4
7	80,000	0	-		1	0.3	77.8	21.8
8	60,000	1	108		1	75.3	24.4	0.3
9	600,000	4	150	120-184	4	71.83	27.8	0.6
10	90,000	1	123		1	40.6	58.9	0.5
11	12,000	1	119		1	60.6	39.0	0.4
12	16,000	1	131		1	67.3	32.5	0.3
13	4,200,000	11	124	104-167	15	46.5	53.27	0.51
14	1,300,000	7	143	100-184	12	47.7	51.39	0.91
15	800,000	1	115		4	18.1	72.68	9.25
16	25,000	1	158		4	16.75	73.68	9.58
17	560,000	9	119	106-128	12	49.43	49.35	1.23
18	270,000	1	113		2	11.7	88.25	.05
19	300,000	4	128	116-151	8	28.18	70.83	1.01
20	300,000	2	147	136-158	4	26.54	72.02	1.44
21	500,000	1	128		6	14.92	81.73	3.32
22	800,000	4	119	109-129	7	33.01	62.58	4.42
23	60,000	2	113	106-121	2	56.1	43.45	0.5
24	500,000	1	140		1	56.4	43.0	0.6
25	1,500	0	-		1	24.6	74.8	0.6
26	36,000	1	118		1	77.6	22.1	0.3

Note: Estimated m³ of material are based on air photo analyses and field investigations.

from a 5-m face in an abandoned quarry (Plate 2). Topsoil and iron oxide layers at these exposures averaged 0.8 m in thickness. Textures of sampled material vary greatly in the east and west parts of this zone. Gravel content in the west section ranges from 41 to 70 percent whereas in the east it ranges from a low of less than 1 to 26 percent. Gravels taken from backhoe pits in the east section of the zone may be underlain by sand because a 1-m-thick layer of gravel was observed to overly sand at the quarry site, and by extensive sandy shoreline exposures in Zone 2.

Sampled material averages 26 percent gravel, 72 percent sand and 2 percent silt−clay. The dominant particle size occurs between 1.0 and 0.5 mm forming 25 percent of sieved material. A silt−sand lens noted in a backhoe pit in the east section of Zone 3 contained 7 percent gravel, 61 percent sand and 32 percent silt−clay. The lens, ranging up to 1.2 m in thickness, appears to be localized, tapering off toward the central part of the zone. A study of 7 samples shows petrographic numbers ranging from 102 to 155 and an average of 120.

Zone 4 is located east of St. George's and south of the railway track. It is a terrace deposit, predominantly forest covered with a residential area, ballfield and playground located on the west side. It is approximately 700 m long by 500 m wide and contains an estimated 1,000,000 m³ of material.

Samples collected in this area came from two quarries (thickness exposures of 4 and 8 m), a 1.2-m-deep trench and from two hand-dug pits with depths of 0.6 m. Topsoil and iron oxide layers in this zone average 0.5 m in thickness.

Sand is the dominant component of this zone; particle-size analyses show an average of 3 percent gravel, 93 percent sand and 4 percent silt−clay. The dominant particle size occurs between 0.5 and 0.25 mm comprising 43 percent of sampled material. The petrographic number of one sample has a value of 111.

Plate 2. *Quarry with 5-m-high exposure of stratified sand and minor pebble gravel.*

Zone 5 borders the south side of Little Barachois Brook on the north side of the Trans-Canada Highway (T.C.H). It consists of an esker ridge and terrace material in an area overgrown by dense forest and with minor bog and barrens. The zone is 800 m long, 500 m wide and contains an estimated 1,280,000 m³ of material.

Samples were collected from three stream exposures with thicknesses of 14 m, 6 m and 4.5 m and two hand-dug pits with depths of 1.8 and 1.9 m. Topsoil and iron oxide layers measured at these sites had an average thickness of 0.6 m.

Particle-size analyses of five samples show 25 percent gravel, 73 percent sand and 1 percent silt−clay. The dominant grain size occurs between 0.5 and 1 mm, forming 26 percent of sieved material. Petrographic numbers range from 101 to 137, with an average of 116.

Zone 6 is situated near the south bank of Little Barachois Brook, between Route 461 and the railway track. It is covered by dense forest except for a small developing residential area at the northwest end. This zone is approximately 500 m long, 200 m wide and contains an estimated 130,000 m³ of material.

One sample was collected in this zone from a 1-m-high road exposure containing 0.7 m of topsoil and underlying iron oxide layer. Particle-size analyses of sampled material indicate that this zone contains 39 percent gravel, 60 percent sand and less than 1 percent silt−clay. The dominant particle size occurs between 0.5 and 1 mm, forming 18 percent of sampled material. A petrographic number of 106 was calculated from the plus 16 mm pebble fraction.

Zone 7 borders the south bank of Little Barachois Brook east of the railway track. It is covered by dense tree growth and a section of abandoned farmland. The zone is 200 m long, 150 m wide and contains an estimated 80,000 m³ of material.

A 2.3-m-high stream exposure in this area showed 0.8 m of topsoil and iron oxide overlying 1 m of sandy, cobbly pebble gravel which, in turn, is underlain by an undetermined thickness of stratified sand−silt sediment. Particle-size analysis of one sample collected from the lower unit shows less than 1 percent gravel, 78 percent sand and 22 percent silt−clay. The dominant grain size occurs between 0.065 and 0.125 mm, making up 30 percent of sampled material. Due to the fine grained nature of sediment in this zone, no petrographic work was conducted.

Zone 8 is located in a forested area between zones 3 and 6 bordering the north side of the railway track. The zone is 100 m long, 600 m wide and contains an estimated 60,000 m³ of material.

A topsoil and iron oxide thickness of 0.5 m was measured at a 1-m-high road exposure. Particle-size analyses of sampled material show an average 75 percent gravel, 24 percent sand and less than 1 percent silt−clay. The dominant grain size occurs between 31.5 and 63 mm, forming 24 percent of sieved material. A petrographic number of 108 was calculated from analysis of this material.

Zone 9 is located on the east side of the railway track, east of Rushy Pond. It is situated in an area of dense forest and cut-overs. This zone is 600 m long, 400 m wide and contains approximately 600,000 m³ of material.

Samples collected in this area came from 4 backhoe pits, averaging 2.9 m in depth. Topsoil and iron oxide layers at these sites ranged from 0.2 to 1.8 m in thickness, averaging 0.93 m. Particle-size analyses of sampled material show an average of 72 percent gravel, 28 percent sand and less than 1 percent silt−clay. The dominant particle size occurs between 16 and 31.5 mm, and forms 21 percent of sieved material. Another 20 percent falls within the 31.5 and 63 mm size range. At two site locations visual observations determined that approximately 30 percent of material is greater than 200 mm (material that is too large for sieving). Petrographic numbers determined from analyses of four samples range from 120 to 184 and average 150.

Zone 10 is situated in a forested area bordering the south side of Rushy Pond, west of the railway track. It is composed predominantly of an esker deposit, dissected by a stream running from Rushy Pond to Big Rushy Pond. The zone is approximately 500 m long, 100 m wide, up to 5 m high and contains an estimated 90,000 m³ of material.

A four-meter road cut through the east end of this zone showed a 0.7 m thickness of topsoil and iron oxide. Sampled material from this exposure indicates this deposit contains about 41 percent gravel, 59 percent sand and less than 1 percent silt–clay. The dominant grain size occurs between 0.5 to 11 mm and 4 to 8 mm; each of these intervals contains 17 percent of sieved material. Another 16 percent was retained between 8 and 16 mm. A petrographic number of 123 was calculated from analysis of one sample.

Zone 11 is a small zone located in a forested area northeast of Rushy Pond, bordering the west side of the railway track. It is 100 m long, 70 m wide and contains an estimated 12,000 m^3 of material.

Material was sampled from a 3.4-m-high road exposure, showing 0.9 m of topsoil and iron oxide overlying gravel. Particle-size analyses show an average of 60 percent gravel, 39 percent sand and less than 1 percent silt–clay. The dominant particle size occurs between 31.5 and 63 mm, forming 23 percent of sieved material. A petrographic number of 119 was calculated from analysis of one sample.

Zone 12 is another small zone located near the northern tip of Rushy Pond. It is covered by dense forest and surrounded by bog. This zone is 250 m long, 15 m wide and contains approximately 16,000 m^3 of material.

One sample was collected from this deposit from a hand-dug pit with an exposure thickness of 2.1 m. This exposure showed 0.8 m topsoil and iron oxide overlying 0.5 m of unsampled sand. Below the sand, a sample was collected from a gravel unit of undetermined thickness. Particle-size analyses of this material shows 67 percent gravel, 33 percent sand and less than 1 percent silt–clay. The dominant grain size occurs between 16 and 31.5 mm, composing 27 percent of sieved material. A petrographic value of 131 was calculated from sampled material.

Zone 13 is located southwest of Shallop Cove and borders the north side of Flat Bay Brook. Approximately 40 percent of this area is overlain by bog with a variable thickness (up to 1.5 m). Dense forest growth, cut-overs and farmland cover the remainder of this zone. This zone is the second most extensive in the study area, covering an area 1500 m long, 100 m wide and containing an estimated 4,200,000 m^3 of material.

Eight of the fifteen samples collected in this zone came from quarry exposures ranging from 1.8 to 7 m in thickness. Five other samples were taken from backhoe pits averaging 3 m in depth, and two samples were collected along a 6-m shoreline exposure. Sampling in the bogland area was limited to one sample due to difficulty in operating the backhoe machine in wet marshy areas. Average topsoil, iron oxide and organic layers were calculated to be 0.7 m thick, from a range of 0.5 to 1.7 m. Stratified sand and gravel (Plate 3) make up this zone. The upper 0.7 to 4 m contain most of the gravel content whereas the underlying unit (undetermined thickness) is predominantly sand (approximately 75 percent).

Plate 3. *Stratified pebble–cobble gravel and sand along 3-m-high exposure in Zone 13.*

Particle-size analyses show an average of 47 percent gravel, 53 percent sand and less than 1 percent silt–clay. The dominant grain size occurs between 0.5 and 1 mm, accounting for 16 percent of sieved material. Petrographic numbers show a range from 104 to 167 with an average of 128.

Zone 14 is a glaciofluvial terrace deposit located east of Muddy Hole at the mouth of Flat Bay Brook. It is covered by forest, barrens and bogland, and includes an area 1000 m long, 600 m wide and an estimated 2,000,000 m^3 of material.

Samples were collected from three river channels (height of exposures—3 m, 8 m and 8 m), two abandoned quarries (exposures of 2.5 m each) and from one 3-m-deep backhoe pit. Topsoil and iron oxide layers averaged 0.8 m in thickness at these sample sites. Particle-size analyses of twelve samples collected in this zone show 48 percent gravel, 53 percent sand and 1 percent silt–clay. The dominant grain size occurs between 0.5 and 1 mm, composing 16 percent of sampled material. Petrographic results of five samples show a range of petrographic numbers of 100 to 184 and an average of 143.

Zone 15 borders the west bank of Flat Bay Brook in a forested area at the north end of the gypsum mine. It is composed of a glacial moraine deposit approximately 1200 m long, 100 m wide and contains an estimated 800,000 m^3 of material.

Four samples were collected in this zone; from a 5-m-high quarry face (Plate 4) and from a 12-m-high river cut. Topsoil and oxide layers average 0.6 m in thickness. Particle-size analyses show 18 percent gravel, 73 percent sand and 9 percent silt–clay. Silt–clay percentages varied from 2 to

e **4.** *Five-m-high exposure of sandy, silty till in adoned quarry at Zone 15.*

ercent. The dominant grain sizes occur between 0.25 and mm, comprising 22 percent of sampled material. A ographic number of 115 was calculated from analysis of sample in this zone.

Zone 16 comprises a small esker ridge located in a sted area near the south bank of Flat Bay Brook, north ne gypsum mine. It is approximately 60 m long, 20 m e and varies from 1 m to 8 m high. It contains oximately 25,000 m³ of material overlain by an average oil and iron oxide thickness of 0.8 m.

Particle-size analyses of four samples collected from two choe pits show an average 17 percent gravel, 74 percent l and 10 percent silt–clay. The dominant grain size occurs veen 0.125 and 0.25 mm, comprising 20 percent of pled material. Another 18 percent was retained in the sieve tion between 0.5 and 0.25 mm. A petrographic number 58 was calculated from analysis of one sample.

Zone 17 is located south of Route 403, bordering the north west sides of Longbyes Pond. It comprises an esker ridge plex overlain by barrens and dense tree growth. Topsoil iron oxide layers range from 0.5 to 2.1 m in thickness an average of 1 m. The major part of this zone consists 2000-m-long esker ridge having varying widths of 10 5 m and heights 3 to 8 m. The remainder of the zone ides smaller esker ridges less than 300 m long and 5 m plus outwash material bordering these eskers. This zone ains an estimated 560,000 m³ of material.

Sampling in this zone was conducted entirely by backhoe. se pits were usually dug along the sides of the esker due to difficulty in getting the backhoe machine over the steep sided ridges. Eleven pits were dug, averaging 3 m in depth.

The granular composition of this zone, determined by particle-size analyses of sampled material, showed 49 percent gravel, 49 percent sand and 1 percent silt–clay. Sieves greater than 0.25 mm contained an average of 10 to 13 percent whereas those below 0.25 mm accounted for less than 2 percent of total sieved material.

Although the average percentages of major textural groups were fairly even, the particle-size composition of the zone does vary. The east section is composed of an estimated 30 percent of unsievable boulder–cobble material, noted in four of the backhoe-dug pits. The west half had more noticeable pebble–cobble material. Sand lenses (less than 1 m in thickness) were noted at two sample sites plus outwash sands along the base of the esker deposits. Petrographic results of nine samples show numbers ranging from 106 to 128 with an average of 118.

Zone 18 is located south of Route 403 in a forested area bordering the west side of the gypsum mine. It is approximately 200 m long, 200 m wide and contains an estimated 270,000 m³ of material.

Material in this zone is overlain by 0.1 m of silt and 1.5 m of pebble–gravel having root debris throughout. Particle-size analyses of two samples collected from a 9-m-quarry exposure (Plate 5) indicate that this zone contains approximately 12 percent gravel, 88 percent sand and less than 1 percent silt–clay. The dominant particle size occurs between 0.5 and 1 mm, containing 38 percent of sieved material. A petrographic number of 113 was calculated from analysis of one sample.

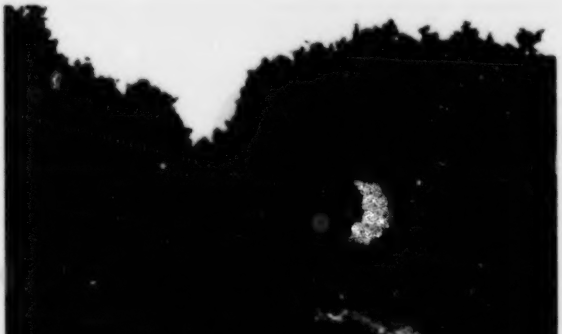


Plate 5. *Nine-m-high quarry exposure in Zone 18.*

Zone 19 is located in a forested area near the southwest border of the gypsum mine. It comprises an esker complex containing an estimated 300,000 m³ of material. Several kettle holes are located between the eskers.

Samples were collected from three backhoe pits averaging 3.8 m in depth and from one 10-m-lake-shore exposure. Topsoil and iron oxide layers have an average thickness of 0.5 m. Particle-size analyses of eight samples show an average 28 percent gravel, 71 percent sand and 1 percent silt−clay. The dominant particle size occurs between 0.5 and 1 mm, comprising 27 percent of sieved material. Petrographic results of four samples show numbers ranging from 116 to 151 with an average of 128.

Zone 20 is located in a forested area bordering the south end of the gypsum mine. This zone is 600 m long, 200 m wide and contains an estimated 300,000 m³ of material. Samples collected in this area came from three quarries with exposed thicknesses of 3, 6 and 7 m. Topsoil and iron oxide thickness at these sites averaged 0.8 m.

This is basically a sand deposit with minor pebble content and pebble−cobble lenses. Particle-size analyses of four samples averaged 27 percent gravel, 72 percent sand and 1 percent silt−clay. The dominant particle size occurs between 0.25 and 0.5 mm,forming 33 percent of sieved material. Petrographic numbers obtained from analyses of two samples are 136 and 158.

Zone 21 is a glaciofluvial terrace located in a forested area near the southeast corner of the gypsum mine. It is approximately 700 m long, 100 m wide and contains an estimated 500,000 m³ of material. Samples were collected from four backhoe pits with average depths of 3.6 m. Cave-in of loose sandy material prevented digging deeper pits at two locations. Topsoil and iron oxide layers average 0.6 m in thickness at these sample sites.

Particle-size analyses of six samples show, on average, 15 percent gravel, 82 percent sand and 3 percent silt−clay. The dominant particle size occurs between 0.25 and 0.5 mm, forming 29 percent of sieved material. Over 60 percent of all sieved material from this zone falls between 0.125 and 1.0 mm. Petrographic results of one sample from this zone had a number of 128.

Zone 22 is located in a forested area southeast of the gypsum mine. It is approximately 700 m long, 70 m wide and contains an estimated 800,000 m³ of material. Sample sites in this area include a 14-m-high quarry face, two backhoe pits (3 m and 4.9 m in depth) and a 2.5-m stream-cut. Topsoil and iron oxide layers measured at these sites averaged 1 m in thickness.

Particle-size analyses of seven samples show 33 percent gravel, 63 percent sand and 4 percent silt−clay. The silt−clay percentage is predominantly due to a sample taken from a 4-m-thick unit, containing approximately 30 percent silt−clay, near the base of a 14-m-high quarry exposure. The domin grain size determined by averaged sample analyses occ between 0.25 and 0.5 mm. This interval forms 15 percen the sampled material. The top two meters of this zone overlain by a cobble−pebble layer showing 67 percent gra size clasts. The remainder of the exposure has alternate lay of finer grain gravels, sand and sand−silt material (Plate Petrographic results of four samples show numbers rang from 109 to 129 and an average of 118.

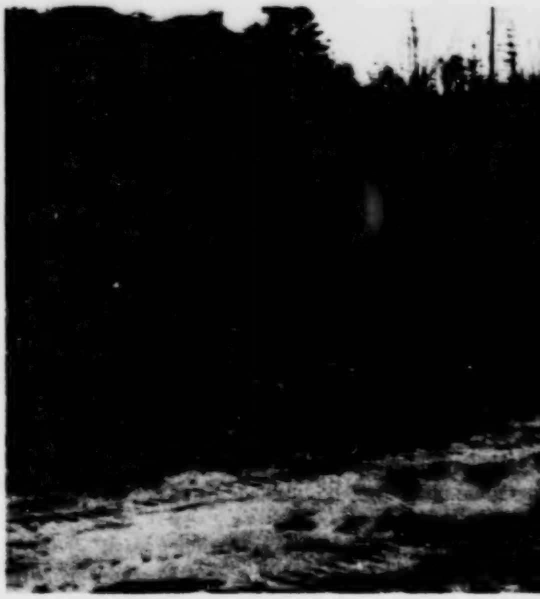


Plate 6. *Fourteen-m-high quarry exposure showing strati gravel and sand in Zone 22.*

Zone 23 is located in a barren and forested area eas the gypsum mine and east of Zone 22. It consists of an es ridge approximately 200 m long, varying in width fron to 35 m, not greater than 5 m high and contains an estima 60,000 m³ of material. Topsoil and iron oxide thickne measured from a 1.4-m hand-dug pit and a 3-m backhoe averaged 1 m. Particle-size analyses of two samples sh on average, 56 percent gravel, 43 percent sand and less t 1 percent silt−clay. The dominant grain size occurs betw 31.5 and 63 mm and between the 1 and 2 mm sieve fractio Each of these contain 17 percent of sieved mater Petrographic numbers of 106 and 121 were calculated fr analyses of two samples.

Zone 24 is located in a dense forested area 2 km of the gypsum mine and 1.5 km south of Route 403. I composed of two esker ridges with a total length approxiamtely 3000 m, up to 40 m wide and a maxim height of 13 m. This deposit contains in excess of 500, m³ of material. Due to dense forest growth and the dista from roads, less time was used to define the boundarie this zone. Topsoil and iron oxide thickness measured i

1.8-m hand-dug pit was 0.6 m. Boulders at the base of the pit prevented further penetration by pick and shovel. Silt layers covered some of these boulders and water seepage into the pit occurred at a depth of 1.6 m.

Particle-size analyses of sampled material show an average 56 percent gravel, 43 percent sand and 0.6 percent silt−clay. The dominant grain size occurs between the 2 and 4 mm sieve fractions, comprising 17 percent of sieved material. A petrographic number of 140 was calculated from analysis of this sample.

Zone 25 is situated in a barren area between zones 22 and 23, east of the gypsum mine. It is the smallest zone sampled in the study area, containing approximately 1,500 m^3 of material. It consists of an esker ridge 150 m long, 10 m wide and 4 m high. One sample, collected from a 2.7-m backhoe pit, showed 1 m of topsoil and iron oxide overlying 1 m of compacted, unsampled sand and pebble−gravel. A 0.7-m-thick sand−pebble material at the base of the pit contained 24 percent gravel, 75 percent sand and less than 1 percent silt−clay. The dominant grain size occurs between 0.5 and 1 mm, comprising 28 percent of sieved material. No petrographic analysis was conducted due to lack of material between 16 and 32 mm.

Zone 26 is located in a forested area near the east side of the gypsum mine, between zones 17 and 22. It is another small deposit, approximately 200 m long, 60 m wide and up to 6 m high. This zone contains an estimated 36,000 m^3 of material, overlain by 0.7 m of topsoil and iron oxide. Particle-size analysis of one sample collected from a 6-m-high stream exposure indicates that the sample contains 78 percent gravel, 22 percent sand and less than 1 percent silt−clay. The dominant grain size occurs between 8 and 16 mm, comprising 19 percent of sieved material. Another 18 percent occurs between the 31.5 and 63 mm sieve fraction. A petrographic number of 118 was calculated from sampled material in this zone.

SUMMARY

Potential aggregate extraction areas were sampled in 26 locations to locate a source of material for export. Approximately 500,000 m^3 is required on a annual basis for almost ten years to ensure economic viability. Many of the zones sampled are small and cannot support such a large mining operation.

Aggregates are a high volume, low-cost material. Some of the smaller zones can be utilized if larger nearby zones are put into production. Several smaller zones bordering the gypsum mine are within one kilometer of each other and, because of the road network around the mine, these zones are easily accessible. The added expense of constructing access roads to more distant areas such as zones 23, 24 and 25 would make them less profitable.

Particle-size analyses indicate a high sand content in many zones, usually greater than 70 percent. Zones with a higher gravel content are small and do not have the required volume of material to support a large extraction operation for coarse aggregate. If only coarse material is required, the sand content must be screened and dumped. This would greatly reduce deposit potential and result in wastage (unless another outlet can be found) of high quality sand-sized material.

Petrographic analysis was only conducted on samples with particle-sizes between 16 and 32 mm. Sand-size material will usually have high petrographic numbers because lighter deleterious materials are washed away as coarser material is broken down leaving behind higher percentages of hard silicate minerals. Most petrographic numbers of samples analyzed are within the range (less than 130) required for use in high quality concrete.

Zones 2 and 13 appear to be the most suitable sites for the aggregate export market. Both zones have large volumes of material and good petrographic characteristics. Zone 2 is less than 1 km away from the loading wharf. A conveyor system could easily be used to transport aggregate over this distance, avoiding potential problems with local traffic. Zone 2 is in close proximity to zones 3 and 4. These two smaller zones could also be utilized to sustain production over a longer time period if necessary.

Zone 13 is located 0.5 km from the haul-road and another 3.5 km from the loading wharf. Although it contains less than half the volume of material of Zone 2, it is still a substantial deposit. Its proximity to Zone 14 plus easy access to many smaller zones around the gypsum mine increases its potential.

ACKNOWLEDGMENTS

The author wishes to thank Martin Batterson, Fred Kirby and David Proudfoot for making a critical review of this report. Joel Mejilla provided capable field assistance, enduring the long days of field traversing despite hot and humid weather. Mr. and Mrs. Mejilla are thanked for their hospitality while working in the Corner Brook area.

REFERENCES

ADI Limited

1986: Study of markets for aggregate materials accessible from Nova Scotia and New Brunswick. Submitted to Supply and Services Canada (DSS File 02GS.23/230-5-0003). ADI Limited, Fredericton, New Brunswick, 348 pages.

Bragg, D.

1986: Reconnaissance study of bedrock aggregate potential for offshore and industrial use. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 297-301.

Brookes, I.A.
1974: Late-Wisconsin glaciation of southwestern Newfoundland (with special reference to the Stephenville map area). Geological Survey of Canada. Department of Energy, Mines and Resources, Paper 74-40, 31 pages.

Canadian Standards Association
1973: CSA Standards A23.1–A23.2, A23.4, Rexdale, Ontario.

Kirby, F.T., Ricketts, R.J. and Vanderveer, D.G.
1983: Inventory of aggregate resources in Newfoundland and Labrador, information report and index maps. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-2, 36 pages; and Open File Maps NFLD. 1287 and Labrador 602.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 389-395

DETAILED LAKE SEDIMENT SURVEYS FOR GOLD AND ASSOCIATED ELEMENTS IN WESTERN LABRADOR

James Butler
Geochemistry and Geophysics Section

ABSTRACT

In 1986, detailed lake sediment geochemical surveys were conducted in three areas of potential gold mineralization in western Labrador. The areas were selected from reconnaissance lake sediment data collected by the Geological Survey of Canada several years earlier. The approximately 500 samples collected in this survey were analyzed by atomic absorption spectrophotometry and multi-element neutron activation methods. Analysis of the results from this survey outline anomalous sites in each of the survey areas.

INTRODUCTION

Detailed lake sediment geochemical surveys, with a sample density of 1 site per 3 km², were conducted in 1986 to follow up three areas of potential gold mineralization in western Labrador. Reconnaissance lake sediment surveys (Geological Survey of Canada, 1982a,b) had shown these areas to be enriched in potential gold-pathfinder elements, such as As, Hg, Ag, Cd, Co, Zn and Cu (Thomas and Butler, 1987). The three areas (Figure 1), referred to as 1) Sawbill Lake area, 2) Menihek Lakes area and 3) McPhadyen River area, are underlain by high-grade Archean rocks of the Ashuanipi Complex between Labrador City in the south and Schefferville, Quebec, in the north. Recent discoveries of significant gold prospects in rocks of similar age about 70 km northwest of Schefferville make the geochemically anomalous areas particularly attractive.

GENERAL GEOLOGY

The Sawbill Lake area was mapped by Rivers (1980). His mapping focused on rocks of the Labrador Trough and, therefore, the Archean Ashuanipi Complex is mapped in much less detail than in its northern areas. The geology of the sample area consists of granulite-grade, undifferentiated, banded, migmatitic and orthopyroxene-bearing, ferromagnesian and granitoid gneisses.

The northern part of the Ashuanipi Complex, which includes the Menihek Lakes and McPhadyen River areas was mapped by Percival (1987). The northern follow-up areas contain a series of granulite-grade metamorphic rocks, mainly migmatitic gneisses, consisting of metasedimentary mafic rocks and homogeneous granitoid rocks. Tonalite and garnet–orthopyroxene–biotite diatexite cut the migmatites. Later intrusions include orthopyroxene–biotite diatexite, granite and syenite.

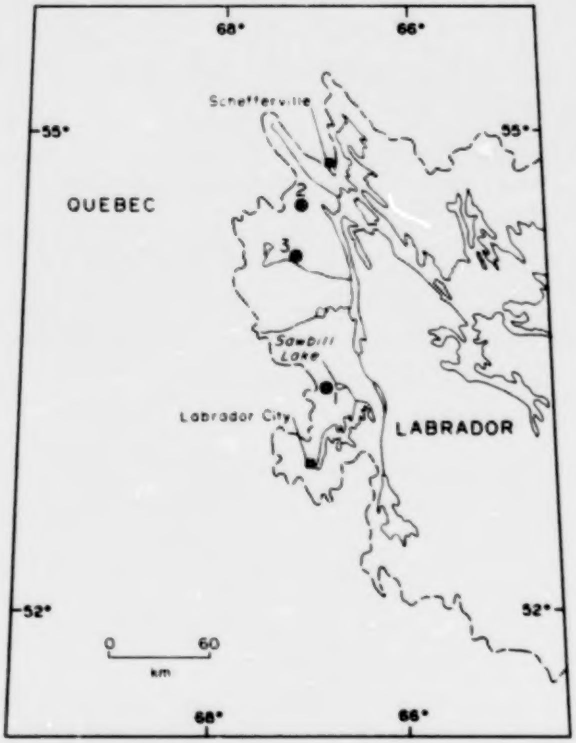


Figure 1. *Index map showing areas of detailed lake sediment surveys.*

The three surveyed areas are generally similar, and have approximately 300 m of topographic relief. The hilltops are usually barren and contain abundant outcrop. The valleys and low-lying areas are till covered and forested or contain bogs. Glacial features are abundant throughout the area. Klassen and Thompson (1987) have recorded five phases of glaciation and recognize a general east to southeast trend as the predominant glacial movement direction.

LAKE SEDIMENT GEOCHEMISTRY

Sample Collection, Preparation and Analysis

The lake sediment samples were collected using the method described by Butler (1980). The samples were air dried in the field and on racks in the laboratory. To complete the drying, the samples were heated to 40 degrees C in drying ovens. They were then screened through 180 micrometre stainless-steel sieves. The less than 180 micrometre fraction (less than 80 mesh) was analyzed.

The elements Cu, Pb, Zn, Co, Ni, Ag, Cd, Mn, and Fe were determined by atomic absorption spectrophotometry following sample digestion in a 4M HNO_3–1M HCl acid mixture. Background correction was applied for Pb, Co, Ni, Ag and Cd determinations. Loss on ignition (LOI), an indication of the organic content of the sample, was determined by ashing the samples for three hours at 500 degrees C. Wagenbauer *et al.* (1983) describe these analytical methods in more detail.

Becquerel Laboratories Incorporated of Mississauga, Ontario, analyzed the samples for Sb, As, Ba, Br, Ce, Cs, Cr, Eu, Au, Hf, La, Lu, Mo, Rb, Sm, Sc, Se, Ag, Na, Ta, Tb, Th, W, U, Yb and Zr using a multi-element technique of analysis by neutron activation and delayed neutron counting. Davenport (1987) discusses the reliability of these data. The 27 site duplicates for Au (Figure 2) have a correlation coefficient of 0.075 and show a scattered plot.

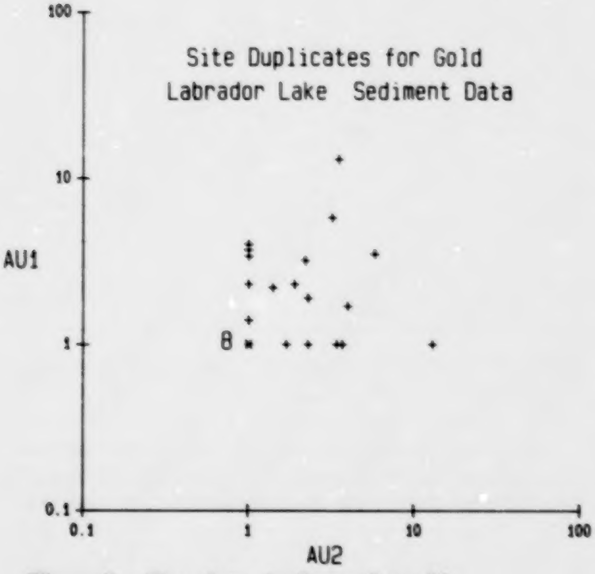


Figure 2. *Plot of site duplicates for gold.*

Data Presentation

Maps of the gold distribution for each of the three areas are present in Figures 3 to 5. The data have been subdivided into three classes, based on the percentiles obtained from the cumulative frequency plot (Figure 6). In Figures 3 to 5, a small plus sign indicates the sample site. The contour intervals are two primary intervals (solid lines with contour values added) and one secondary contour interval (broken or dashed lines). The plotting and contouring package used was the USGS Plotgen Program (supplied by Gerald Evenden).

Statistics

Summaries of statistics of the data are presented for individual areas in Table 1. This table includes the geometric mean (GEO MEAN), $\log_{10}$ standard deviation (LOG10 STD DEV), range and the number of cases for the samples collected. Most elements have a coefficient of variation greater than 50 percent (Table 2), indicating that their distributions are not normal, and they are better represented by a log-normal distribution. Loss on ignition (LOI) and W has a coefficient of variation less than 50 percent, indicating that their distributions are approximately normal. Zinc has a coefficient of variation of 50 percent.

Table 3 presents the Pearson correlation matrix for all the data. All data have been $\log_{10}$ transformed into a normal distribution, except W and loss on ignition (LOI). Correlation of residual (R) values have also been calculated for As, Ba, Co, Cr, Cu, Ni and Sc and are included in Table 2. There are strong associations of Cu, Pb, Zn, Co, Ni, As with Fe and Mn and with each other. These correlations appear particularly strong in the Sawbill Lake area. These associations reflect the effect of coprecipitation of these metals with Fe and Mn oxides and hydroxides in the lakes. Antimony shows very little correlation with Au, As or indeed any other element. Gold has a weak association with W, U, Cr and Cu. There is also a strong association of Ba with Au, As, Co, Cr, Cu, Mo, Ni, Pb, Sc, Zn, Fe and Mn. The majority of these correlations is also shown in the residuals, particularly Au with residual As, Ba, Cr, Cu, Ni and Sc.

Interpretation

Sawbill Lake area. An area of high Au values is concurrent with high As values slightly to the east of Lac Boujonnier (Figure 3). The Au values of four samples in this area range from a low of 3.7 mg/t to a high of 10 mg/t. This area is also coincident with a topographic lineament.

A few one-point anomalies of Cu, Pb and Zn occur in the area but some anomalies coincide with more than one element. In particular, an area in the southwest near Lac Boujonnier, as well as an area to the northeast, near the top of the map area, is high in Cu and Zn. These areas are moderately high in Mn as well, indicating probable scavenging of base metals.

Menihek Lake area. One sample, about 1 km from the Quebec–Labrador border, is high in Au (13 mg/t); there are a number of samples in the 5 mg/t range, and one of 10 mg/t nearby (Figure 4). This area also correlates with As and Ba

Table 1. Summary statistics for the sample areas shown in Figures 3 to 5. Values are expressed as grams per tonne except where indicated.

	Sawbill Lake Data				Menihek Lakes				McPhadyen River			
ELEMENT	GEO MEAN	LOG 10 STD DEV	RANGE	CASES	GEO MEAN	LOG 10 STD DEV	RANGE	CASES	GEO MEAN	LOG 10 STD DEV	RANGE	CASES
Au (mg/t)	0.65	0.296	0.50– 10.00	92	2.07	0.426	0.05– 13.00	172	1.07	0.226	0.50– 12.00	233
As	0.54	0.282	0.10– 41.00	92	1.33	0.377	0.38– 135.00	172	0.85	0.335	0.27– 41.60	233
Ba	127.40	0.266	35.00– 1400.00	92	208.90	0.254	39.00–1200.00	172	0.06	0.283	0.02– 0.37	233
Cd	2.10	0.252	0.10– 1.90	93	0.38	0.239	0.10– 1.10	172	32.00	0.195	8.03– 153.00	234
Co	7.70	0.379	1.00– 67.00	93	12.70	0.351	2.00– 100.00	172	3.00	0.239	1.00– 18.00	234
Cr	53.10	0.248	11.00– 180.00	92	77.62	0.240	12.00– 264.00	172	61.23	0.210	28.00– 243.00	234
Cu	26.18	0.206	1.00– 163.00	93	36.31	0.161	15.00– 104.00	172	199.50	0.243	45.00– 1100.00	233
Mo	3.72	0.567	0.20– 28.00	92	4.19	0.277	0.20– 26.00	172	0.26	0.244	0.10– 1.50	234
Ni	25.90	0.263	1.00– 137.00	93	42.46	0.174	13.00– 153.00	172	10.90	0.348	1.00– 414.00	234
Pb	4.80	0.299	1.00– 27.00	93	3.94	0.268	1.00– 19.00	172	3.03	0.244	9.10– 170.00	233
Sb	0.06	0.426	0.02– 2.10	92	0.06	0.283	0.02– 0.89	172	6.81	0.193	0.20– 37.00	233
Sc	5.25	0.220	1.40– 18.10	92	7.29	0.214	1.80– 22.30	172	35.60	0.178	8.00– 193.00	234
Zn	94.40	0.341	1.00– 36.00	93	124.74	0.175	35.00– 251.00	172	98.17	0.166	1.90– 17.20	233
W	0.23	0.176	0.20– 1.20	92	0.67	0.425	0.20– 13.00	172	0.90	0.260	0.20– 8.80	233
U	0.60	0.390	0.20– 29.10	92	1.35	0.307	0.20– 22.00	172	0.58	0.425	0.20– 12.00	233
Fe (%)	1.04	0.430	0.01– 9.67	93	1.51	0.370	0.10– 16.96	172	127.90	0.495	14.00–107600.00	234
Mn	109.10	0.584	1.00–89300.00	93	129.70	0.417	17.00–5600.00	172	1.36	0.370	0.11– 15.58	234
LOI (%)	38.58*		7.20– 74.00	93	32.32*		3.80– 70.70	172	30.94*		4.80– 80.00	232

* Arithmatic mean

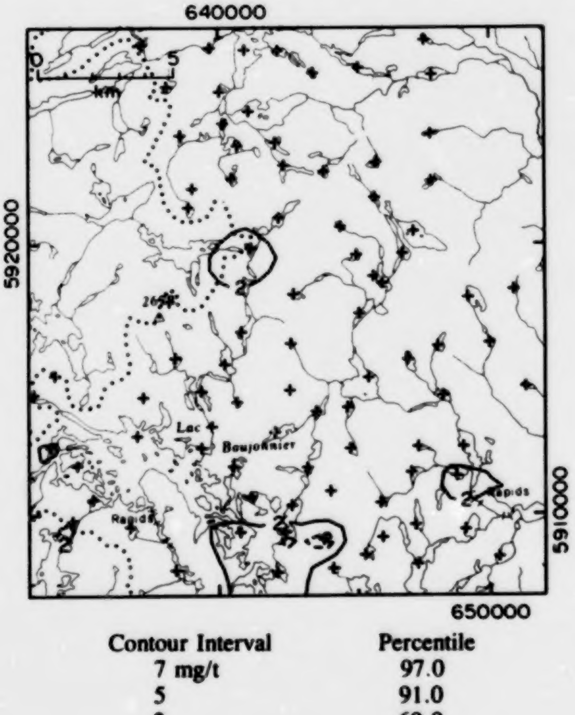
NOTE: mg/t = milligrams per tonne

Table 2. Summary statistics for combined areas of lake sediment survey in Labrador

	Mean	Median	Std Dev	Coeff Var	Geo Mean	Log 10 Std Dev	Range	Cases
Au	2.111	0.50	3.002	142.2	1.25	0.434	0.50 – 51.00	498
As	1.730	0.69	6.717	100.3	0.91	0.365	0.10 – 135.00	498
Ba	230.602	190.00	177.250	388.3	187.50	0.270	35.00 – 1400.00	498
Cd	0.393	0.30	0.252	76.9	0.33	0.265	0.10 – 1.90	500
Co	16.010	10.00	24.338	573.0	10.69	0.366	1.00 – 414.00	500
Cr	73.950	72.00	36.911	152.0	64.71	0.238	9.10 – 264.00	498
Cu	35.612	32.00	18.871	49.9	31.77	0.210	1.00 – 163.00	500
Mo	6.703	5.50	4.989	53.0	5.06	0.367	0.20 – 37.00	498
Ni	39.854	37.00	20.803	74.4	35.56	0.213	1.00 – 193.00	500
Pb	4.330	4.00	3.054	52.2	3.56	0.272	1.00 – 27.00	500
Sb	0.082	0.07	0.117	70.5	0.06	0.311	0.02 – 2.10	498
Sc	6.695	6.00	3.373	148.7	5.93	0.217	1.40 – 22.30	498
Zn	116.124	107.00	52.140	50.4	104.23	0.221	1.00 – 367.00	500
W	0.871	0.55	1.253	44.9	0.51	0.426	0.20 – 13.00	498
U	1.339	0.93	1.985	143.9	0.95	0.327	0.20 – 29.10	498
Fe	1.953	1.31	2.050	105.0	1.33	0.387	0.01 – 16.96	500
Mn	674.520	114.50	6313.334	936.0	124.45	0.488	1.00–107600.00	500
LOI	32.469	31.95	10.448	32.2			3.80 – 80.00	498

NOTE: Std Dev = standard deviation, Coeff Var = coefficient of variation, Geo Mean = geometric mean, Log 10 Std Dev = $\log_{10}$ standard deviation

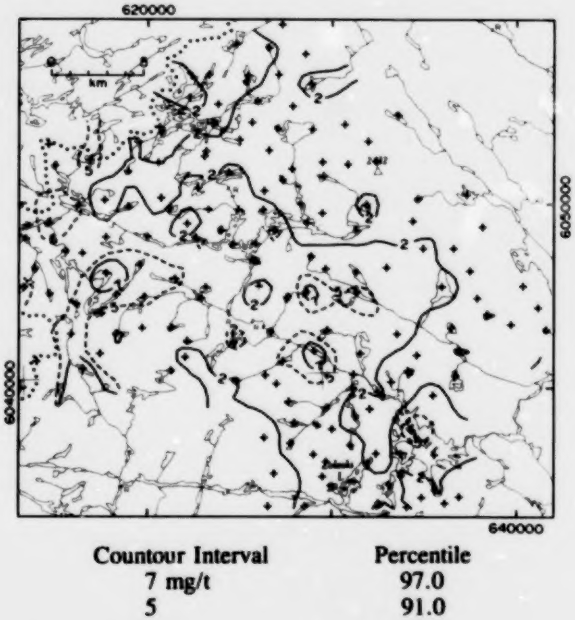
Data values are expressed as grams per tonne except where indicated



Contour Interval	Percentile
7 mg/t	97.0
5	91.0
2	60.0

+ Sample sites

Figure 3. *Gold distribution in lake sediments, Sawbill Lake, Labrador (NTS 23G/7).*



Countour Interval	Percentile
7 mg/t	97.0
5	91.0
2	60.0

+ Sample sites

Figure 4. *Gold distribution in lake sediments, Menihek Lakes, Labrador (NTS 23J/6,7,10 and 11).*

Table 3. Pearson correlation coefficients (x100) for all data from Labrador lake sediment survey. All elements, except W and loss on ignition, have been $\log_{10}$ transformed (n = 498).

	Au	As	RAs	Ba	RBa	Cd	Co	RCo	Cr	RCr	Cu	RCu	Mo	Ni	RNi	Pb	Sb	Sc	RSc	Zn	W	U	Fe	Mn
As	42																							
RAs	36	81																						
Ba	33	39	08+																					
RBa	24	08+	11	82																				
Cd	-01*	26	14	-17	-37																			
Co	29	58	05*	58	07*	26																		
RCo	19	13	16	17	21	05*	39																	
Cr	34	46	05*	70	34	14	74	20																
RCr	22	07*	10	44	54	02*	12	31	64															
Cu	32	51	23	18	-16	44	57	11	56	20														
RCu	22	25	29	-13	-17	42	13	16	17	25	84													
Mo	09+	26	00*	08+	-22	15	44	07*	24	-16	47	27												
Ni	36	58	21	59	24	26	79	32	75	38	71	42	35											
RNi	27	24	31	27	34	11	25	50	33	53	45	53	05*	73										
Pb	18	34	07*	25	-03*	50	51	12	51	25	46	26	24	45	16									
Sb	-01*	00*	04*	-16	-16	16	-06*	-02*	-07+	-03*	08+	15	13	00*	05*	13								
Sc	38	48	09+	69	35	24	74	24	90	52	57	21	22	75	35	52	-02+							
RSc	28	12	15	44	53	17	15	35	50	77	24	30	-15	39	53	27	05*	68						
Zn	30	51	13	36	-04*	51	71	14	68	24	72	42	43	80	45	58	14	69	29					
W	22	41	34	20	09	-01*	32	27	23	06	22	10	18	29	18	09	-07*	21	05*	23				
U	31	41	22	32	11	28	45	23	48	25	53	37	23	52	33	34	07+	62	45	54	18			
Fe	25	54	-02*	53	-02*	18	86	-05*	75	-02*	58	05*	44	68	04*	46	-07*	72	-02*	69	24	41		
Mn	18	55	-01*	53	-02*	31	87	-04*	63	-01*	51	05+	41	68	03*	48	-03*	62	02	65	19	33	83	
LOI	-12	-11	04*	-55	-49	37	-34	-19	-32	-17	12	34	03*	-23	-07*	-02+	26	-28	-12	-07*	-05*	-09+	-28	-24

+ not significant at the 98% confidence level

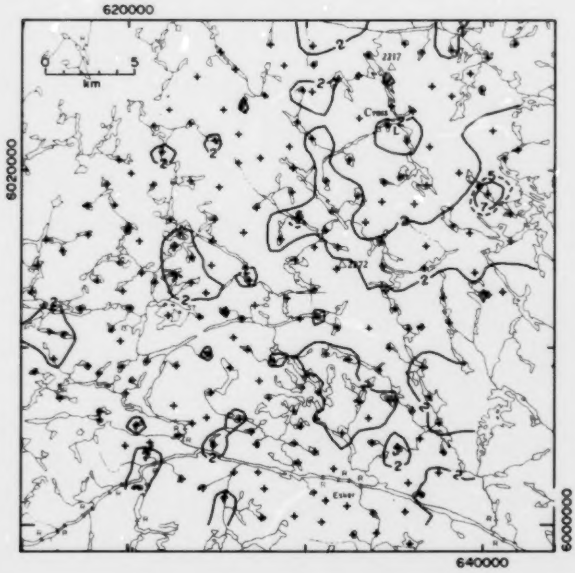
* not significant at the 95% confidence level

NOTE: n = number of samples

anomalies. Rock samples from the vicinity of the lake containing the 13 mg/t value show a range of values from 80 mg/t to 515 mg/t (McConnell *et al.*, 1987). Detailed soil sampling has also been completed in this area.

Numerous Cu, Pb and Zn anomalies occur throughout the area, but are usually associated with no more than one or two sample sites. A few of these anomalies are concurrent with each other. Only one sample has a value in Cu greater than 100 g/t. Mn and Fe are generally low and scattered.

McPhadyen River area. Gold values are more scattered than in other areas, but several sites of 7.5 mg/t and a high of 12 mg/t occur in the area (Figure 5). Most of these high Au values concur with As anomalies.



Contour Interval	Percentile
7 mg/t	97.0
5	91.0
2	60.0

+ Sample sites

Figure 5. *Gold distribution in lake sediments, McPhadyen River, Labrador (NTS 23J/2,3,6, and 7).*

The central part of this area has Cu values between 60 and 150 g/t. These are concurrent with Zn anomalies in the same area, however, this central area also has moderate Mn and Fe values.

DISCUSSION

The geometric mean value for Au, in the areas sampled in this survey, vary from 2.07 mg/t in the Menihek Lakes area to 0.65 mg/t in the Sawbill Lake area. The overall mean for the areas is 1.25 mg/t, which compares well with mean values for Au from the Port aux Basques and White Bay areas of insular Newfoundland. These areas have shown mean values for Au to be 1.21 and 1.38 mg/t respectively (Davenport and Nolan, 1987). Arsenic, however, has a much lower mean value in the Labrador data (0.91 g/t) than in the island data (3.73 and 1.98 g/t), but is highest in the Menihek Lakes area at 1.33 g/t. Barium, which also correlates well with Au, has an overall mean of 187.5 g/t and is highest in the Menihek Lakes area. Only Pb, Cd and LOI are higher than the overall mean in the Sawbill Lake area. Gold, along with As, Pb, Zn and Cu are higher than the overall mean in the Menihek Lakes area. The mean for almost all elements, except Cu, Ni and Mo, in the McPhadyen River area, rank between the other two area.

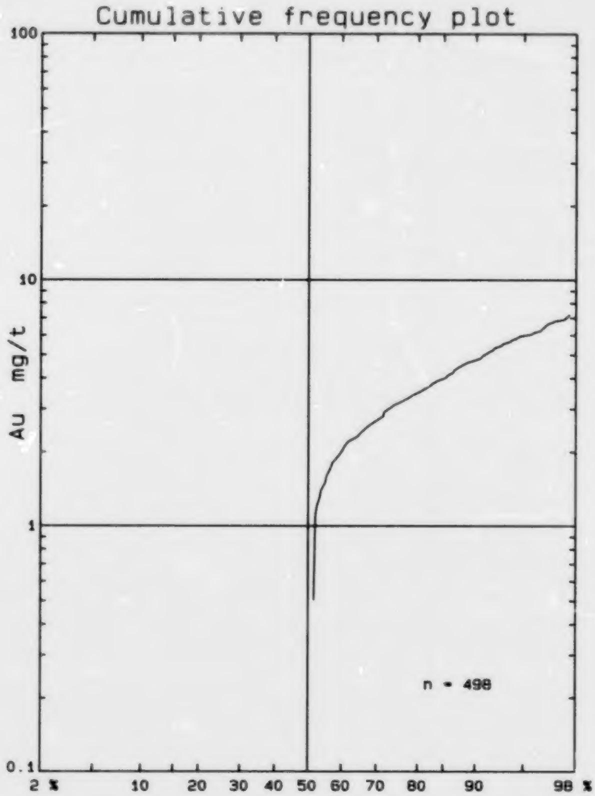


Figure 6. *Cumulative frequency distribution plot of Au for the sample areas.*

CONCLUSIONS

Based on this survey, and on the results of detailed soil and rock sampling in this area by McConnell *et al.* (1987), the Menihek Lakes area (Figure 3) is the most favourable target for detailed exploration for gold. The McPhadyen River area also has several anomalies and has produced several high values in rock samples (Thomas and Butler, 1987). The statistics are similar to, but lower than, the Menihek Lakes area. The Sawbill Lake area has one anomaly, near Lac Boujonnier, which coincides with a topographic lineament and has a value of 10 mg/t. The chemistry of the Sawbill Lake area is different from the other two areas and may indicate a difference in the geology. The anomalous area near Lac Boujonnier should be explored in more detail.

ACKNOWLEDGMENTS

The co-operation and field assistance of Lyne Houle, Louise Daley and Craig Cummings is gratefully acknowledged. The flying and navigational skills of Steve Hemphill, our pilot, was much appreciated. While in Schefferville, accommodations were shared with Andy Thomas and his field crew. They are thanked for their co-operation and assistance. Constructive criticism by Peter Davenport greatly improved the quality of this report.

REFERENCES

Butler, A.J.
1980: Lloyd's River area, southwest Newfoundland. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-1, pages 230-239.

Davenport, P.H.
1987: Increasing usefulness of lake sediment geochemistry to mineral exploration. *In* Report of Activities, Newfoundland Department of Mines, Mineral Development Division, pages 96-99.

Davenport, P.H. and Nolan, L.W.
1987: Gold and associated elements in lake sediment from regional surveys in the Port aux Basques area (NTS 11O) and the White Bay area (NTS 12H/9, 10 11, 15 and 16; 12I/1). Newfoundland Department of Mines, Mineral Development Division, Open File NFLD (1582).

Geological Survey of Canada
1982a: Regional lake sediment and water geochemistry reconnaissance data, NTS 23G, Labrador. Geological Survey of Canada, Open File 903.

1982b: Regional lake sediment and water geochemistry reconnaissance data, NTS 23J, Labrador. Geological Survey of Canada, Open File 904.

Klassen, R.A. and Thompson, F.J.
1987: Ice flow history and glacial dispersion in the Labrador Trough. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 61-71.

McConnell, J.W., Whelan, G. and Newman, L.
1987: Bedrock gold analyses and geology of metalliferous areas of the Ashuanipi Complex, Western Labrador. Newfoundland Department of Mines, Mineral Development Division, Open File LAB (735).

Percival, J.A.
1987: Geology of the Ashuanipi granulite complex in the Schefferville area, Quebec. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 1-15.

Rivers, C.J.S.
1980: Geology of the Sawbill Lake area, Labrador (23B/7). Newfoundland Department of Mines and Energy, Mineral Development Division, Map 80-2.

Thomas, A. and Butler, J.
1987: Gold reconnaissance in the Archean Ashuanipi Complex of western Labrador. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 237-255.

Wagenbauer, H.A., Riley, C.A. and Dawe, G.
1983: Geochemistry laboratory. *In* Current Research, Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 133-137.

Current Research (1988) Newfoundland Department of Mines,
Mineral Development Division, Report 88-1, pages 397-401

SURFICIAL GEOCHEMICAL SURVEYS OF AURIFEROUS PORTIONS OF THE ASHUANIPI COMPLEX, WESTERN LABRADOR

John W. McConnell and Lisa A. Newman
Geochemistry and Geophysics Section

ABSTRACT

The authors conducted the following surveys in those areas of the Archean Ashuanipi Complex defined by previous workers to have a high potential for gold mineralization: (1) soil and stream sediment sampling in the vicinity of lakes containing anomalous contents of gold in their sediment, (2) high-density lake sediment surveys in areas where gold-associated elements such as arsenic, silver and base metals were anomalous in reconnaissance surveys, and (3) sampling and analyzing bedrock samples, including many sulphide-bearing rocks, for gold. Of 172 samples, eight had analyses of 100 to 1875 ppb gold. Multi-element analyses of all samples are in progress.

INTRODUCTION

The discovery of gold mineralization in granulite-grade Archean rocks of the Ashuanipi Complex (Lapointe, 1986) 70 km northwest of Schefferville in Quebec has led to considerable exploration activity in the northern portion of the complex (Figure 1). Work on the Labrador portion of the complex in 1986 by Thomas and Butler (1987) identified several areas having above average abundances of gold in bedrock. They selected areas for study that had anomalously high concentrations of possible gold-pathfinder elements (including As, Ag, Cu, Hg, Mo and Zn) in reconnaissance lake-sediment samples (Geological Survey of Canada, 1982a,b). Recent detailed work by Butler (1987) indicated locally high contents of gold in lake sediment. Percival (1987) also recognized auriferous zones from geological mapping at 1:250,000 scale of the northern half of the complex.

The field program involved the application of several sampling approaches—soil, stream sediment, lake sediment and bedrock. Generally, soil, stream and rock sampling were done in areas that were suspected to be in close proximity to gold mineralization. Lake sediments were collected from areas having regional indications of possible gold mineralization.

LOCATION AND ACCESS

The Labrador portion of the Ashuanipi Complex is located in westernmost Labrador. The area is accessible by float plane from Schefferville, Québec or Wabush—Labrador City, Labrador or by helicopter from Goose Bay, Labrador. It is also possible, though difficult, to gain access to much of the eastern portion by boat from Menihek or Esker, both of which are accessible by road and train. The Québec North Shore and Labrador Railway services Labrador City and Schefferville from Sept-Iles. The Labrador towns are also serviced by Canadian Airlines and Québec Air. Schefferville can be reached by scheduled flights from Wabush.

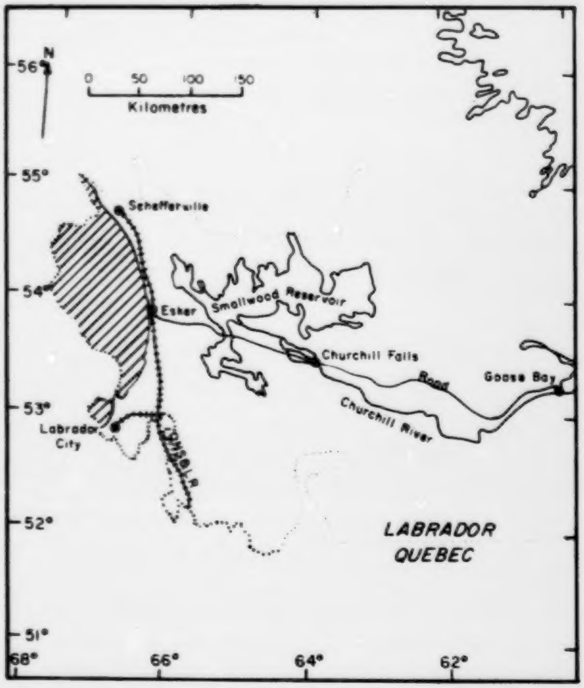


Figure 1. *Location map of Ashuanipi Complex (diagonally lined area).*

OUTLINE OF FIELD PROGRAM

Field work during 1987 exploited results of the previous work and focused primarily on 20 areas in which Butler's

---

This project is a contribution to the Canada—Newfoundland Mineral Development Agreement, 1984—1989

(1987) data had disclosed anomalous contents of gold in lake sediment or where Thomas and Butler (1987) or Percival (1987) had found indications of gold in bedrock (Figure 2). Our overall aim was to apply geochemical exploration methods to understand the nature of the distribution of gold and gold-pathfinder elements in the surficial and bedrock environments. Specific aims were to:

1) evaluate the effectiveness of various surficial geochemical exploration methods in reflecting known or suspected gold mineralization;

2) evaluate the significance of gold anomalies in lake sediment;

3) study the character of the dispersion of gold and related trace elements in the surficial and bedrock environments;

4) conduct detailed lake sediment surveys in areas of high gold potential in order to furnish the exploration industry with new exploration targets;

5) provide a geological framework for interpretation of the surficial geochemistry.

Soil Surveys

Eighteen areas were selected for study and 925 samples of B-horizon soil were collected. Most areas were chosen for their proximity to lakes with anomalous gold values (6 to 13 ppb Au) (Butler, 1987), because of the presence of gold in bedrock (Thomas and Butler, 1987) or to outline the extent of newly discovered sulphide zones.

Survey designs included conventional grid sampling, single-line detailed sampling across mineralized zones and 'loop' sampling. The last-named describes a procedure of sampling around the perimeter of an anomalous lake in an effort to identify the source of metals; where practical, this was done in conjunction with stream sediment sampling of inflowing streams.

There are problems associated with working in a glaciated landscape, the foremost of which is determining the provenance and transport history of the sampled material. Klassen and Thompson (1987) recognized up to 5 directions of glacial advance in the Schefferville area with an easterly to southeasterly one predominating. Our observations in the area south and west of Schefferville support their conclusion of a dominantly easterly ice flow. In several of the study areas, the widespread homogeneity of the underlying bedrock makes it difficult to estimate the provenance and transport distance of pebbles from till. Landforms and the degree of sorting of tills are factors in selecting sample sites; in particular, water-sorted and esker deposits were avoided.

When they become available, the geochemical data from the soils should provide an indication of transport directions and distances.

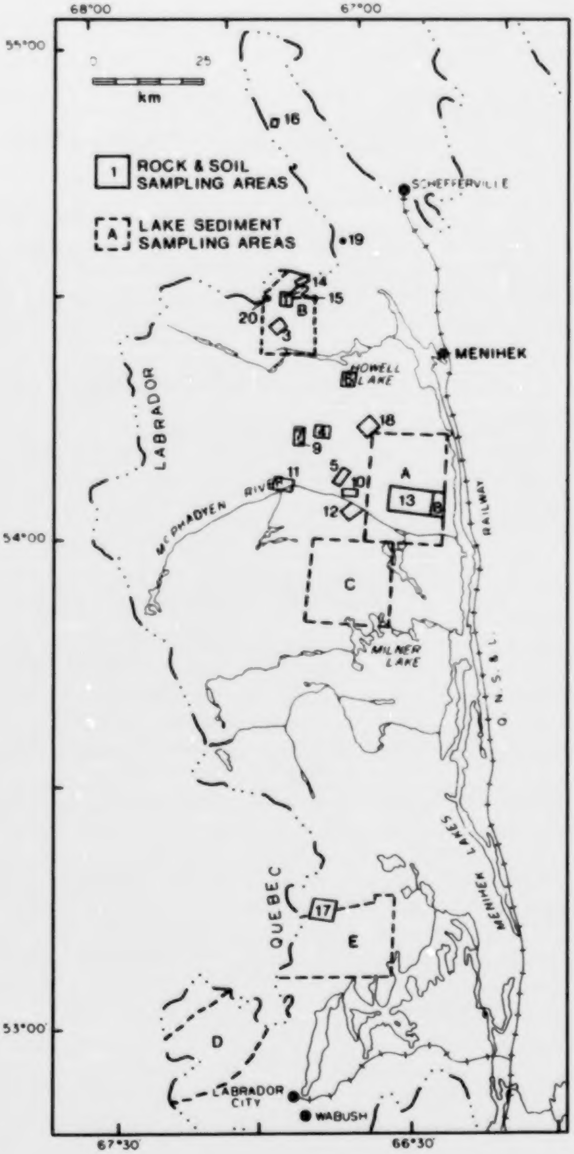


Figure 2. *Locations of study areas.*

Stream Sediment Surveys

Samples of active sediment were obtained to complement soil surveys around anomalous lakes, to obtain fill-in data from soil grids and to obtain data where soil sampling was not practical. Among the last group were stream sediment surveys conducted along lineaments and fault systems that were suspected of being auriferous on the basis of previous lake sediment surveys. Unfortunately, several of the 78 original samples were subsequently destroyed in a laboratory fire resulting from an equipment malfunction.

Lake Sediment Surveys

Lake sediment samples were collected at 621 sites from five areas that had been identified from the reconnaissance lake-sediment data (Geological Survey of Canada, 1982a,b) as having high contents of such gold-sympathetic elements as arsenic, silver and mercury (Figure 2). Analyses of these may define additional gold ± base-metal targets.

Bedrock Sampling and Mapping

Several of the study areas were mapped and all but one were sampled. The scale of mapping varied from 1:2,500 to 1:50,000 according to the abundance of outcrop, the size of the area and the time available. Nearly all sulphide (gossan) zones encountered were sampled and numerous samples of apparently unmineralized country rock were also obtained.

ANALYSES

Sample Preparation

Soil and sediment. These samples were field-dried and then oven-dried at 40°C. Soils were seived to -63 microns and the fine fraction retained for analyses. Stream sediments were seived and the -180 micron fraction retained for analyses. Lake sediments were disaggregated with a rubber hammer before being seived to -180 microns.

Rock. Samples were processed initially through a jaw-crusher and then pulverized in a tungsten-carbide shatterbox. Such treatment precludes obtaining meaningful cobalt and tungsten analyses.

Analytical Methods

Several methods are being employed to obtain chemical analyses; these are summarized in Table 1. Analyses for gold are being done by Becquerel Laboratories using instrumental neutron activation analysis (INAA) with a nominal detection limit of 1 ppb Au. This non-destructive method also gives useful analyses of 24 other elements (Davenport, *this volume*). Rock samples were also analysed for gold by fire assay/atomic absorption spectrometry (FA/AA, Chemex Laboratories) with a 5 ppb detection limit.

PRELIMINARY RESULTS

To date, only gold analyses (FA/AA) for rocks are available. These data have been released (McConnell *et al.*, 1987) along with geological descriptions of the areas, to which the reader is referred for more detail.

Geological Summary

The 8500 km² of the Ashuanipi Complex in Labrador comprises a roughly oval area of high-grade, migmatitic gneisses and younger, variably homogeneous and foliated intrusive rocks. The plutons range from granodiorite to tonalite, to charnockite. The area is transected by two sets of lineaments; a dominant one trending 130°, which controls drainage to the southeast, and another trending northeast. Overall, regional structures trend northwest and have moderate to steep northeast dips. On a 500-m to 1-km scale, folds are commonly upright and open with shallowly plunging to horizontal fold axes.

Table 1. Analytical methods and element suites

Sample Type	Method and Element Suite
Soil	INAA, AA, LOI
Stream Sediment	INAA, AA, LOI
Lake Sediment	INAA, AA, LOI
Rock	FA/AA, INAA, AA, AA (oxides)

INAA:	As, Au, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Na, Rb, Sc, Se, Sm, Ta, Tb, Th, U, W, Yb, Zr
AA:	atomic absorption spectroscopy; Ag, Cd, Co, Cu, Fe, Mn, Mo, Ni, Pb, Zn
FA/AA:	fire assay/atomic absorption; Au
LOI:	loss-on-ignition as estimate of organic content
AA (oxides):	major and minor element oxides by AA
Note:	AA, AA (major) and LOI are determined in the departmental laboratory using methods described by Wagenbauer *et al.* (1983).

Garnet–orthopyroxene–biotite–plagioclase ± K-feldspar–quartz assemblages predominate throughout, reflecting granulite-grade metamorphism (Percival, 1987). Locally, upper-amphibolite-facies rocks occur in the south, and granulite-grade rocks are partially retrograded to greenschist facies where they are associated with Grenvillian thrusting. Occurrences of disseminated to massive sulphides, dominantly pyrite, are widespread.

Gold Analyses

The 172 rock samples were analysed for Au by FA/AA using a 10-g aliquot. As a check on analytical precision and accuracy, duplicates and standards of known gold content were included. With the exception of one duplicate pair, the duplicates are satisfactory although most are below the detection limit (Table 2). The standard samples also reproduced satisfactorily (Table 3).

Some statistical measures of the distribution of Au analyses are summarized in Table 4. Geometric means and log standard deviations are used to minimize the influence of the strongly positively skewed distribution. For comparative purposes, samples are grouped into those

Table 2. Analytical duplicates (ppb Au) of rock samples using FA/AA

Sample Pair	Analysis #1	Analysis #2
1	<5	<5
2	<5	25
3	<5	<5
4	<5	<5
5	<5	<5
6	<5	10
7	10	20

Table 3. Analytical standards used for Chemex Au analyses (ppb).

Standard Sample	Accepted Value	Analytical Results	
GTS-1	346	320	390
CH-1	240	200	210
CH-2	1330	960	1130

exhibiting visible sulphides and those not. It is apparent both from Table 4 and from the histograms in Figure 3 that the higher gold analyses tend to be associated with sulphide-bearing rocks, although Au values up to 80 ppb are encountered in rocks lacking visible sulphides. These data from sulphide-free rocks suggest that background levels of gold in these areas are uncommonly high.

Eight samples had analyses equal to, or exceeding, 100 ppb Au; these are listed in Table 5. Most of these samples are from outcrops where the extent of visible mineralization, as revealed by the presence of gossans, is very restricted, usually forming patches less than 1 m in diameter. However, samples 144 and 99 are from a zone about 1 m wide that can be traced in excess of 100 m before disappearing under surficial cover. Sample 34 is from a small outcrop in an otherwise largely till-covered area. At the time of writing (November, 1987), the areas around some of these sample sites had recently been staked.

The release of complementary soil and stream sediment data from the vicinity of most of these rock samples may give a better understanding of the extent of mineralized zones. Some preliminary soil data indicate that gold from mineralized bedrock is being reflected in the soil chemistry. These data may be smoother and more representative of the bedrock than the analyses of bedrock grab samples that are more prone to being influenced by the 'nugget effect'.

Table 4. Summary statistics of gold analyses in rocks (ppb)

Sample Set	N	$\bar{X}$	$\bar{X}$ + 1 S.D.	Minimum*	Maximum
All samples	172	4.7	20	2	1875
Sulphide-free rocks	59	2.7	5.9	2	80
Samples with visible sulphides	113	6.3	32	2	1875

* Values below detection limit are assigned a value of 2 ppb.

N – number of samples

$\bar{X}$ – geometric mean

SD – standard deviation

Table 5. Rock analyses and descriptions listed in order of decreasing gold content

Sample Number	Au (ppb)	Grid Number	NTS	U.T.M. Easting	U.T.M. Northing	Comments
57	1875	3	23J11	615900	6040375	1% sulphides
34	1200	16	23J14	605775	6088750	0.5% pyrite
109	550	7	23J06	620650	6020150	5% pyrite, trace graphite
13	515	1	23J11	618450	6045700	trace pyrite
99	400	9	23J06	624022	6012921	1% pyrite, trace chalcopyrite
55	130	1	23J11	617825	6044900	0.5% pyrite
7	100	1	23J11	617300	6046550	trace sulphides
155	100	9	23J06	623981	6012920	5% pyrite, trace chalcopyrite

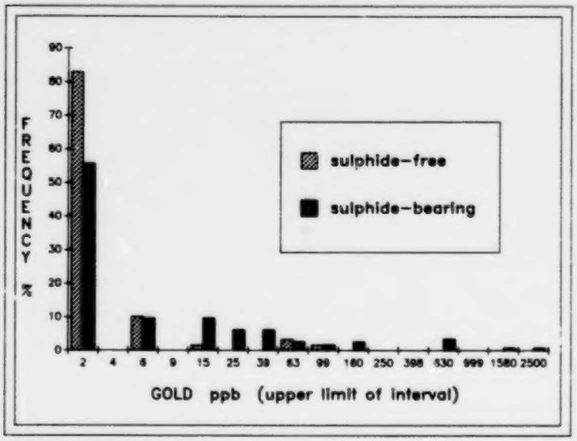


Figure 3. *Histograms of gold in sulphide-free rocks and in sulphide-bearing rocks.*

ACKNOWLEDGMENTS

The field work required for the preparation of this report would not have been possible without the assistance of many individuals. Gerry Whelan undertook most of the bedrock mapping and John Percival of the Geological Survey of Canada provided us with an introduction to the geology of the area and drew our attention to the sulphide zone known in this report as Area 14. Karen Patey, Mike Regular and Craig Cummings of Memorial University provided able field assistance. Gaetan Viens and Jacques Levesque of Universal Helicopters provided outstanding service. Gaetan must be credited with the discovery of Vien's Vein, or Area 9 as it is more prosaically described here. Ed Montague is thanked for greasing the logistical wheels in Wabush. Tyson Birkett and his crew from the Geological Survey of Canada are particularly thanked for installing the sample collection and transport system at base camp. Finally, Peter Davenport is acknowledged for critically reviewing the manuscript.

REFERENCES

Butler, J.
1987: Detailed lake sediment surveys in western Labrador for gold and associated elements. Newfoundland Department of Mines, Mineral Development Division, Open File Lab 716, 16 pages.

Davenport, P.D.
This volume: The use of multi-element neutron activation analysis of organic lake sediment in geochemical exploration for gold.

Geological Survey of Canada
1982a: Regional lake sediment and water geochemistry reconnaissance data, NTS 23G, Labrador. Geological Survey of Canada, Open File 903.

1982b: Regional lake sediment and water geochemistry reconnaissance data, NTS 23J, Labrador. Geological Survey of Canada, Open File 904.

Klassen, R.A. and Thompson, F.J.
1987: Ice flow history and glacial dispersion in the Labrador Trough. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 61-71.

Lapointe, B.
1986: Reconnaissance geologique de la region du lac Paillerant, Territoire du Nouveau Québec. Ministere du l'Energie et des Resources, Gouvernement du Québec, MB 85-73, 11 pages.

McConnell, J., Whelan, G. and Newman, L.
1987: Bedrock gold analyses and geology of metalliferous areas of the Ashuanipi Complex, western Labrador. Newfoundland Department of Mines, Mineral Development Division, Open File Lab 735, 16 pages.

Percival, J.A.
1987: Geology of the Ashuanipi granulite complex in the Schefferville area, Québec. *In* Current Research, Part A. Geological Survey of Canada, Paper 87-1A, pages 1-10.

Thomas, A. and Butler, J.
1987: Gold reconnaissance in the Archean Ashuanipi Complex of western Labrador. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 237-255.

Wagenbauer, H., Riley, C.A. and Dawe, G.
1983: Geochemical laboratory. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 133-137.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 403-414

THE USE OF MULTI-ELEMENT NEUTRON ACTIVATION ANALYSIS OF ORGANIC LAKE SEDIMENT IN GEOCHEMICAL EXPLORATION FOR GOLD

P.H. Davenport
Geochemistry and Geophysics Section

ABSTRACT

Gold in organic lake sediment is a useful guide to areas of gold potential at the regional scale, although background and threshold values are low (<1 and 4 mg/t Au, respectively). Direct neutron activation analysis (NAA) of lake sediment can provide gold analyses adequate for geochemical exploration, and, in addition, gives data on a large number of other elements (e.g., Ag, As, Ba, Br, Cd, Ce, Co, Cr, Cs, Eu, Fe, Hf, Hg, Ir, La, Lu, Mo, Na, Ni, Rb, Sc, Se, Sm, Sn, Ta, Tb, Te, Th, U, W, Yb, Zn and Zr). The method has the advantage of being nondestructive.

The results of NAA analyses of about 1500 lake sediment samples from Newfoundland and Labrador, including a large number of replicates and control reference samples, indicate that the method provides good quality data for As, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Mo, Na, Ni, Rb, Sc, Sm, Ta, Tb, Th, U, Yb and Zn. The detection limits for Ag, Cd, Hg, Ir, Sn and Te are too high to measure their abundances in typical lake sediment. Data for Se, W, Au and Zr are quite significantly truncated by their detection limits, but are still of value in geochemical exploration. The results for Co, Fe, Mo, Ni and Zn by NAA compare well with data acquired by atomic absorption; NAA data for Ba, Ce, La, Th and Zr show good overall correlations with results by ICP/OES.

Although the technique is nondestructive, when material is irradiated and analyzed a second time by NAA, long-lived isotopes lead to spuriously high results for elements such as Co, Cs, Eu and Sc. For Au, this 'memory' effect is negligible, and by reanalyzing the same material it is possible to isolate analytical variability from sample variability due to inhomogeneity. In general, organic lake sediment is remarkably homogeneous in its Au content, strongly suggesting that most of the Au is evenly dispersed (adsorbed ?) throughout the material.

INTRODUCTION

Direct neutron activation analysis (NAA) is capable of measuring, at reasonable cost, Au abundances in organic lake sediment at levels low enough to measure dispersion patterns from Au deposits (McConnell, 1987; Davenport and Nolan, 1987). As typically offered by commercial laboratories, the method provides data for over 30 elements in addition to Au: e.g., Ag, As, Ba, Br, Cd, Ce, Co, Cr, Cs, Eu, Fe, Hf, Hg, Ir, La, Lu, Mo, Na, Ni, Rb, Sb, Sc, Se, Sm, Sn, Ta, Tb, Te, Th, U, W, Yb, Zn and Zr for the results discussed here. In this article, the quality and usefulness of these multi-element data in lake sediment for geochemical exploration will be discussed, as well as some features of the method and suggestions for an approach to monitoring analytical quality and assuring analytical consistency.

MEASUREMENT AND MONITORING OF ACCURACY AND PRECISION

The determination of absolute accuracy presents considerable problems for most of the elements in the NAA suite, since there are few, if any, reference standards available for many of them, and certainly none of lake sediment. Fortunately, for mapping geochemical patterns in surficial materials, absolute accuracy is not of paramount importance, providing the results for a particular element are directly proportional to the actual levels of the element in the samples, the results are consistent in level from one analytical batch to another, and the reproducibility (precision) for any sample is sufficiently good to allow differences in level between samples to be measured. In the absence of reference materials, the proportionality of results for an element to its real concentration in a sample can be estimated by comparing the results of two different analytical techniques—such as NAA, which depends on the nuclear properties of an atom, and atomic absorption spectrophotometry, which depends upon an atom's electronic properties. The likelihood of two such very different techniques giving closely proportional results by chance is remote.

To monitor the precision and accuracy of NAA analyses of Newfoundland lake sediment, analytical splits and control reference materials were inserted in all batches. In addition, site duplicate samples were included, which allow the

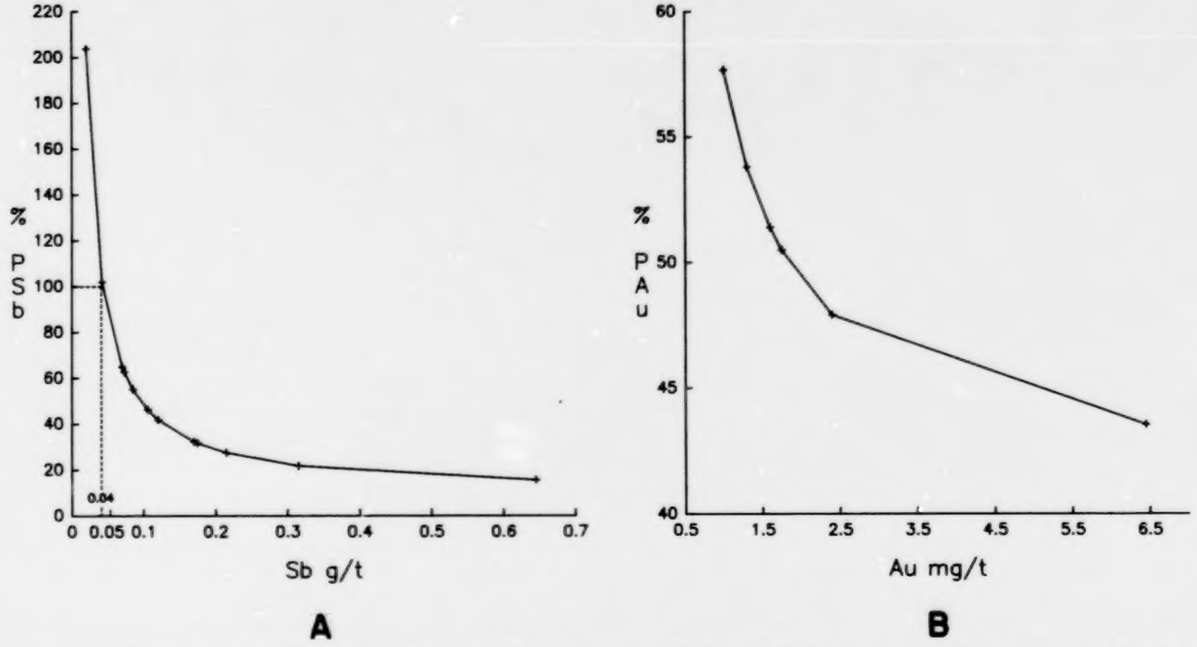


Figure 1. *Plots of precision (PSb, PAu) as a function of concentration for (A) Sb and (B) Au by NAA, based on 136 pairs of replicate analyses. The calculated detection limit (0.04 g/t) where PSb = 100 percent and the quoted detection limit (0.05 g/t) are shown in Figure 1A.*

determination of the combined sampling and analytical variance. Both controls and duplicates were included 'blind'; that is, they were indistinguishable from the normal samples.

Sample Splits

If chosen randomly, the sample splits will comprise a representative subset of the sample suite being analyzed. Being representative, they will give the best measure of analytical reproducibility for the sample set, in contrast to the control reference material, which usually is specially prepared from a different area and from a different medium having a different chemical and mineralogical composition.

Thompson and Howarth (1978) devised a method for calculating analytical precision from duplicate pairs of analyses (at least 50), which recognizes that analytical precision varies with absolute concentration. This approach allows the effective detection limit of the analytical method to be determined in many cases; this detection limit may be higher in the particular sample material being used than that quoted by the laboratory.

Briefly, the method of Thompson and Howarth (1978) involves the following steps:

1) calculate the means and absolute values of the differences of the pairs of duplicate analyses, $(X_1 + X_2)/2$ and $|X_1 - X_2|$ respectively;

2) sort the values in order of increasing mean value;

3) assign the sorted results to groups of eleven, ignoring the last group if it contains less than eleven results;

4) for each group obtain the overall mean concentration and the median difference;

5) calculate the linear regression equation of the median difference (dependent variable) on the mean group value (independent variable); and

6) from the regression equation, the value of the median difference $|X_1 - X_2|$ at any mean concentration Xc can be taken as the standard deviation (s) and the precision (Pc) at that concentration (Xc) is given by $Pc = 200s/Xc$ (at the 95 percent confidence level).

Analytical values less than the detection limit have been set here to a value of one half of the detection limit that was quoted by the laboratory. This leads to a slightly optimistic value for the precision at low levels (Thompson and Howarth, 1978), but this is not regarded as a major problem; the choice of some other value would be even more arbitrary.

Examples of the application of this approach are shown in Figures 1A and 1B for Sb and Au by NAA. These results are based on 136 pairs of laboratory splits from the orientation study of McConnell (1987) in the White Bay area, the analyses of archived samples in the Port aux Basques and White Bay area (Davenport and Nolan, 1987), and the analyses of lake sediment from other parts of Newfoundland and Labrador carried out in 1987. Figure 1A shows a common form of plots of precision with concentration (Fletcher, 1981, Fletcher *et al.*, 1987). The quoted detection limit and the actual detection limit (the concentration where the precision is ± 100 percent) are marked for Sb. In the case of Au (Figure 1B), the rounding of the values below the detection limit has significantly increased the precision measured in this manner, and a true assessment of the actual detection limit is not possible from this approach. Estimates of the detection limits for As, Cs, Co, Eu, Hf, Ni, Rb and Yb can be obtained, however, in addition to that of Sb. The range of values for several other elements in the duplicate samples is generally well above their detection limits, so for these elements too, this approach does not yield estimates of their detection limits.

Although this method gives an overall assessment of analytical precision where a reasonably large number of duplicate analyses (> 50) is available, it is neither particularly useful for monitoring precision, nor for identifying outliers which might indicate the need for reanalysis. This can be done in another way from the results of analyses of laboratory splits.

For each pair of analytical duplicates a precision parameter, p, is calculated from the ratio of the absolute value of the difference between the two values to the mean of the two values,

$$\text{i.e., } p = |X_1 - X_2| \;/\; \tfrac{1}{2}(X_1 + X_2)$$

The value of p is expressed as a percentage, and as in Thompson and Howarth's (op. cit.) approach relates analytical variance to absolute concentration, but for each individual pair rather than generally for all pairs. The values of p can be compared to a table of pre-established tolerances such as in Table 1 for Sb. The tolerances at lower concentrations increase progressively to a value of ± 100 percent (cf. Figure 1A).

In establishing tolerances such as those in Table 1 for a new analytical method, it is necessary to analyze the distribution of p values with concentration. This can be done by assigning the results for the duplicate pairs into four to six groups that span the range of concentrations. For each group the mean and standard deviation of the p values and maximum p value are tabulated. The mean, mean plus one standard deviation and maximum value of p can be plotted against the midpoint value of each group (Figure 2) to obtain a general impression of the relationship between p and concentration. Values for p can then be selected based on what the analytical method can be reasonably expected to achieve. This table of precision tolerances should be compared to the range of concentrations to be measured in the sample set. If the precision over most of observed range of concentrations is not adequate to characterize the geochemical patterns in the data, another method should be sought (if available). In the case of Au, for example, both the precision and the detection limit are higher than is desirable in relation to the observed levels and range of Au in lake sediment, but a better practical alternative is lacking.

Table 1. Tolerances for pairs of replicate analyses for Sb by concentration range.

Concentration Range (g/t)	Tolerance* 'p'
0.1−0.2	100%
0.21−0.5	67%
0.51−1.0	50%
> 1.0	30%

$$*p = \frac{|X_1 - X_2| \times 100\%}{(X_1 + X_2)/2}$$

Where X_1 and X_2 are the first and second values from a duplicate pair of samples.

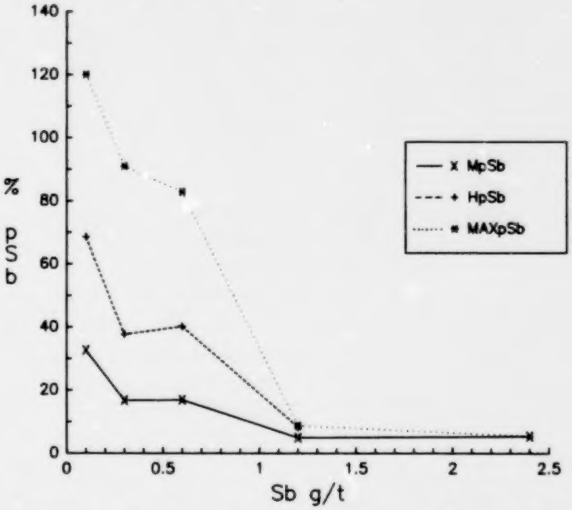


Figure 2. *Plot of difference (pSb) between pairs of Sb values from 136 duplicate samples against their average concentration in five groups (< 0.2, 0.2-0.4, 0.4-0.8, 0.8-1.6, > 1.6). MpSb is the mean difference in each group, HpSb is the mean plus one standard deviation of the differences in each group, and MAXpSb is the maximum (worst) difference between pairs in each group.*

Control Reference Materials

Control reference materials (lake and stream sediment) prepared by the Geological Survey of Canada and the Canadian Centre for Mineral and Energy Technology (GSC/CANMET) and bulk samples of lake sediment prepared by the Newfoundland Department of Mines were used to monitor both precision and batch to batch consistency. Altogether these control reference materials were included 173 times (labelled as though normal samples) throughout the analytical batches. The identity and number of analyses for each of the 19 controls are given in Table 2.

Table 2. Control reference materials used to measure analytical consistency of multi-element neutron activation data.

Source	Sample I.D.	Type of Material	Number of times analyzed
Mineral Development Division	C-21	lake sediment	7
	C-22	lake sediment	14
	C-23	lake sediment	4
	C-24	lake sediment	7
	C-25	lake sediment	3
	C-26	lake sediment	15
	C-27	lake sediment	6
	C-28	lake sediment	12
	C-29	lake sediment	4
	C-30	lake sediment	4
	C-31	lake sediment	2
GSC/CANMET	LKSD-1	lake sediment	11
	LKSD-2	lake sediment	16
	LKSD-3	lake sediment	19
	LKSD-4	lake sediment	19
	STSD-1	stream sediment	13
	STSD-2	stream sediment	12
	STSD-3	stream sediment	2
	STSD-4	stream sediment	3
		TOTAL	173

The results obtained from these controls for Sb, Hf and Au are plotted in Figure 3. For each element the controls are ranked in order of increasing geometric mean value; the geometric mean and a bar extending one standard deviation unit (log) above and below the mean (a one sigma range) are also plotted for each control. The scale bar on the right-hand side indicates a range of ± 0.2 log units about any mean value. For a mean of 100 g/t, the top and bottom of the bar would plot at 158 and 63 g/t respectively; this range is roughly equivalent to a precision of ± 100 percent. Where the one sigma range is greater than this range, it suggests the element concentration is below the effective detection limit.

For Sb (Figure 3A), with the exception of control C-24, the one sigma ranges are all considerably smaller than ± 0.2 log units, and there is a general decrease in the standard deviations with increasing concentration. The control C-24 has two high analyses of 0.23 and 0.35 g/t, compared to the remainder in the range 0.07 to 0.11 g/t. These two high values are based on rather small samples (1.4 g) compared to samples yielding the other results for this control (6.6 to 10.4 g). Three subsequent analyses of this control gave results of 0.11, 0.11 and 0.12 g/t, confirming that the two high results are spurious.

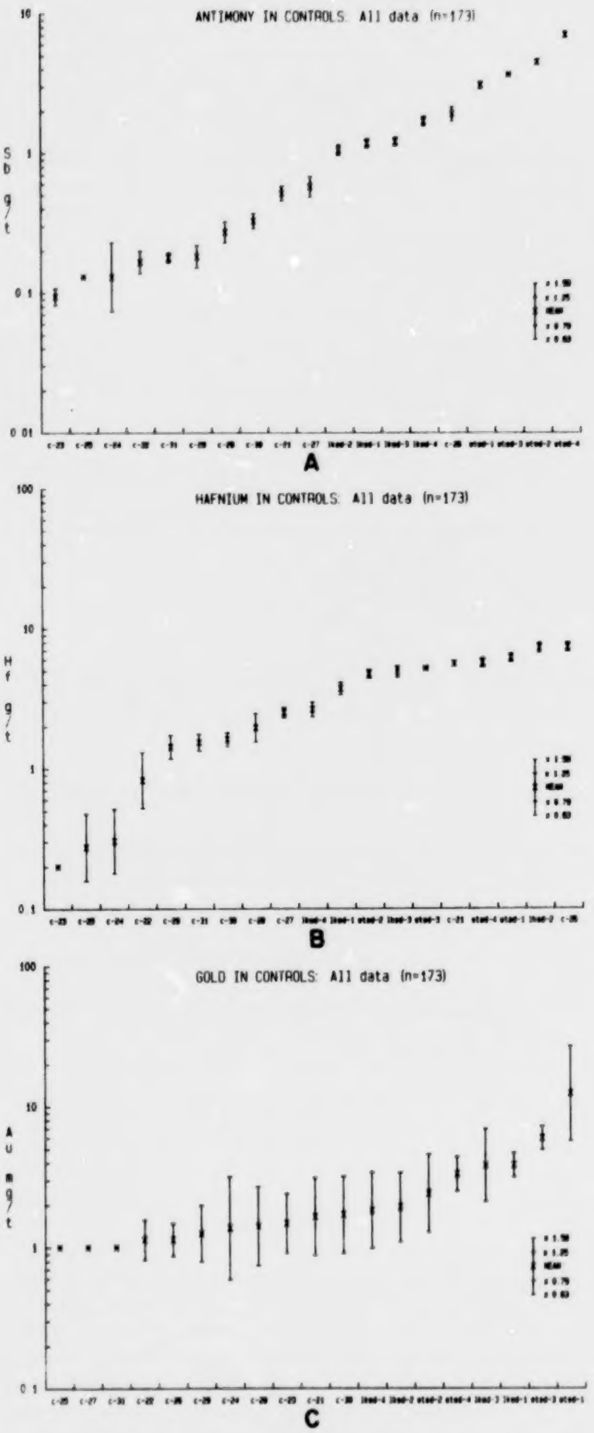


Figure 3. *Plots of geometric means and one standard deviation ranges for (A) Sb, (B) Hf and (C) Au contents in control reference materials (173 samples) used for batch to batch monitoring of accuracy of NAA analyses.*

For Hf (Figure 3B), the precision improves generally from low to high values. The controls C-25 and C-24 have one sigma ranges greater than ± 0.2 log units, indicating that they are below detection limit, whereas control C-22 shows a one sigma range of about ± 0.2, so its mean value of 0.8 g/t is probably close to this limit. Control C-23 has values consistently below detection, and so all values were assigned an arbitrary value of 0.2 g/t, leading to the apparent absence of analytical variance.

Gold (Figure 3C) shows a trend similar to the left side of the plot for the Hf controls (C-23 to C-28). The controls with the lowest Au content (C-25, C-27 and C-31) show no apparent variance, as all values were below the detection limit, and were assigned values of 1 mg/t (cf. control C-23 for Hf, Figure 3B). As the mean values increase from C-22 to C-24, there is an apparent increase in variance. This reflects an increase in the proportion of values above the detection limit to those below. The controls C-26 to STSD-2 show similar and large one sigma ranges, indicating that these controls are below the effective detection limit. Of the five controls with the highest mean Au values, only three (STSD-4, LKSD-1 and STSD-3) have acceptable precision.

The five highest controls have median values of 3.1, 4.6, 3.8, 6.8 and 8.9 mg/t Au, at which levels, from the reproducibility of the laboratory duplicates, precision should be acceptable. This contradiction calls into question the homogeneity of the controls for Au, due to the possibility of the 'nugget' effect. For example, the control STSD-1 is almost certainly inhomogeneous in Au, with values ranging from 4.8 to 44.0 mg/t, and with no obvious outliers. The control is homogeneous for all other elements examined, but its use as a control reference material for Au is dubious. For the control LKSD-3, 19 of 22 values fall in the range 2.1 to 5.9 mg/t Au (median of 4.7 mg/t), but there are three outliers; two values of <1 and one of 11.0 mg/t Au. Outliers occur in the data for STSD-2 (a value of 7.8 mg/t Au compared to its median value of 2.4 mg/t), and for C-24 (a value of 9.3 mg/t Au compared to a median value of <1 mg/t).

These outliers suggest that the controls LKSD-3, STSD-2 and C-24 might also be inhomogeneous, although the outliers could also be due to analytical imprecision. To determine whether control sample inhomogeneity or analytical error was the problem, the capsules containing these controls giving dubious results were relabelled and resubmitted for analysis, together with several other capsules containing controls where consistent Au values had been reported. Altogether 19 capsules of material were reanalyzed.

The possible problems with the carry-over of radioactive isotopes produced in an initial neutron activation on results from a second irradiation and analysis are dealt with later in this report. For Au this is not a very serious problem, as the isotope produced from it during activation has a fairly short half-life. The results for Au from the first and second analysis are listed in Table 3.

Table 3. Comparison of initial Au results by NAA with results from a second irradiation and analysis of the same material after a four-month interval.

Control	1st Au values mg/t	2nd Au values mg/t
C-22	<1	<1
	<1	<1
	<1	<1
	<1	<1
	2.4	<1
C-26	1.8	<1
C-24	<1	<1
	9.3*	11.0*
C-28	3.0	<1
	4.2	<1
C-30	<1	<1
LKSD-2	<1	<1
	<1	<1
STSD-2	7.8*	7.7*
LKSD-3	<1*	4.0
	<1*	5.1
	11.0*	8.2*
LKSD-1	5.2	<1

* outliers

Of the five suspected outliers, all three high values were confirmed on reanalysis of the same sample material. The values for the two low outliers for LKSD-3 on reanalysis (4.0 and 5.1 mg/t Au) are close to the median for the control (4.4 mg/t). For most other samples the second analysis confirmed the earlier determination, although one value of 5.2 mg/t dropped to <1 mg/t on reanalysis. From these results it is apparent that the controls are somewhat inhomogeneous, although probably usable (in contrast to STSD-1). The controls do not provide as good a measure of precision for Au as the laboratory duplicates. Both the control and duplicate data suggest that Au values greater than 6 to 7 mg/t are consistently reproducible. Results between 2 to 4 mg/t are less reliable, as the effective detection limit for Au is in this range, and the effective detection limit for Au in lake sediment by this NAA method is about 2 mg/t.

COMPARISON OF NAA WITH OTHER ANALYTICAL METHODS

Since the control reference materials used have no generally accepted values for Au (or any of the element suite analyzed), analyses of some of the samples by other techniques were carried out to get an idea of how well the

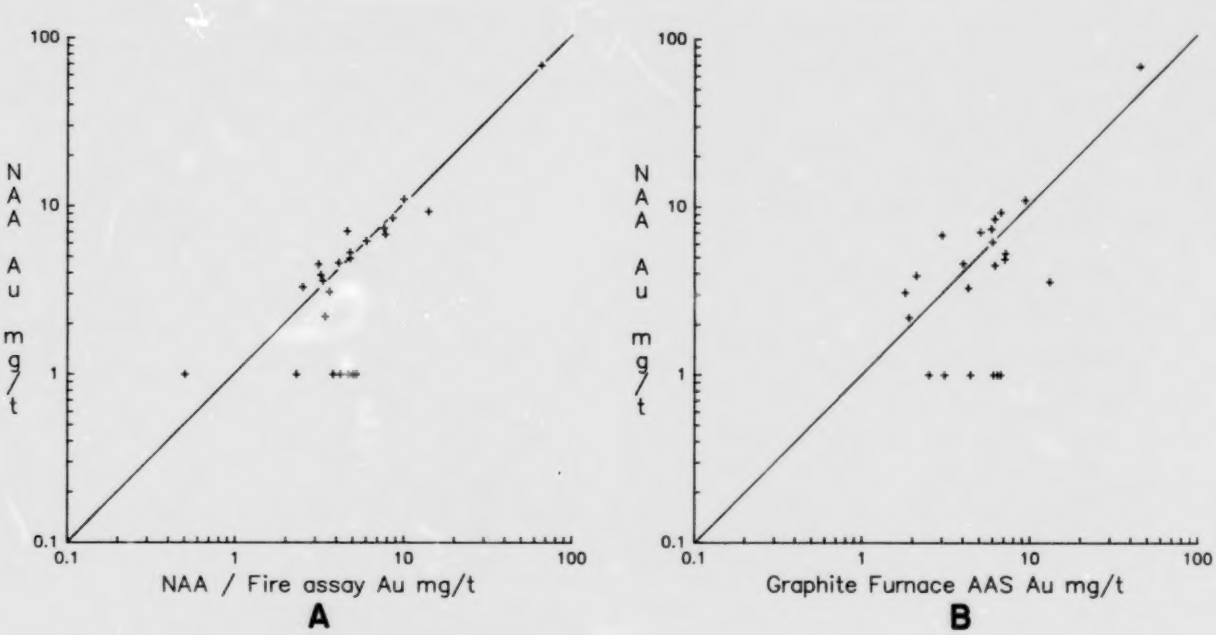


Figure 4. *Plot of Au content analyzed by multi-element NAA against Au content analyzed by (A) neutron activation, fire assay and neutron counting (24 lake sediment samples) and (B) graphite furnace atomic absorption (23 lake sediment samples).*

NAA results compared with these other more widely used methods.

Gold

Two comparative methods were employed for comparison with the NAA data for Au. First, 24 samples were analyzed by a different NAA technique at another laboratory in which the sample (5 to 10 g) was first irradiated, then fire assayed and the resulting doré bead counted. This alternative neutron activation analysis technique can achieve lower detection limits for Au (0.2 mg/t was quoted) as most other elements that interfere with the determination of Au are removed by the fire assay step. Furthermore, as the Au in the sample is irradiated prior to fire assaying, any Au contamination introduced in the flux is not irradiated, and hence cannot influence the Au result.

The results of the two methods are shown in Figure 4A. There is a good correspondence between the methods above about 4 mg/t (overall correlation 0.74). The scatter at low values is probably due both to poor precision and lack of sensitivity by the multi-element method, and increasing problems of sample representivity at these very low levels.

The very sensitive neutron activation, fire assay, neutron counting method may be superior for Au in comparison with the multi-element NAA method, but it has several drawbacks. The sample material is destroyed, it provides data only for Au, and the method is more costly. Moreover, since the technique requires the handling of radioactive material during the fire assay step, it is not really a routine procedure for large numbers of samples.

A second comparison is afforded from the results of 23 of the same samples that were analysed by a graphite furnace, atomic absorption technique, following the digestion of 10 g of sample in *aqua regia*, and extraction of the Au into methyl isobutyl ketone (Figure 4B). There is an overall correlation between the two methods (r = 0.57), but the correspondence is not as good in Figure 4A. A similar plot of the graphite furnace, atomic absorption data against the neutron activation, fire assay, neutron counting data, was similar to Figure 4B (correlation r = 0.55), implying that the two neutron activation methods show the best correspondence.

Atomic Absorption Analysis for Ag, Co, Fe, Mn, Ni and Zn

A total of 1279 lake sediment samples analysed by NAA had been analyzed previously by atomic absorption for the elements Ag, Co, Fe, Mn, Ni and Zn, using the methods described by Wagenbauer *et al.* (1983). Correlations (based on log-transformed data) and the slope and intercept of the regression for the NAA data on the AA data are given in Table 4, and plots for Co, Fe, Mo, Ni and Zn are shown in Figure 5. No plot is included for Ag as there is no significant correlation between the two sets of data; the AA data with a detection limit of 0.2 g/t is considered to be better, as the NAA method has a detection limit of 1 ppm, which is above the 95th percentile for lake sediment in Newfoundland. The very good correspondence between the Co and Fe data suggest that both methods give good data for these elements. The lower correlations for Mo, Ni and Zn are due to the higher detection limit for these elements by NAA, which causes a scatter of points at lower values. For these elements the AA data are better.

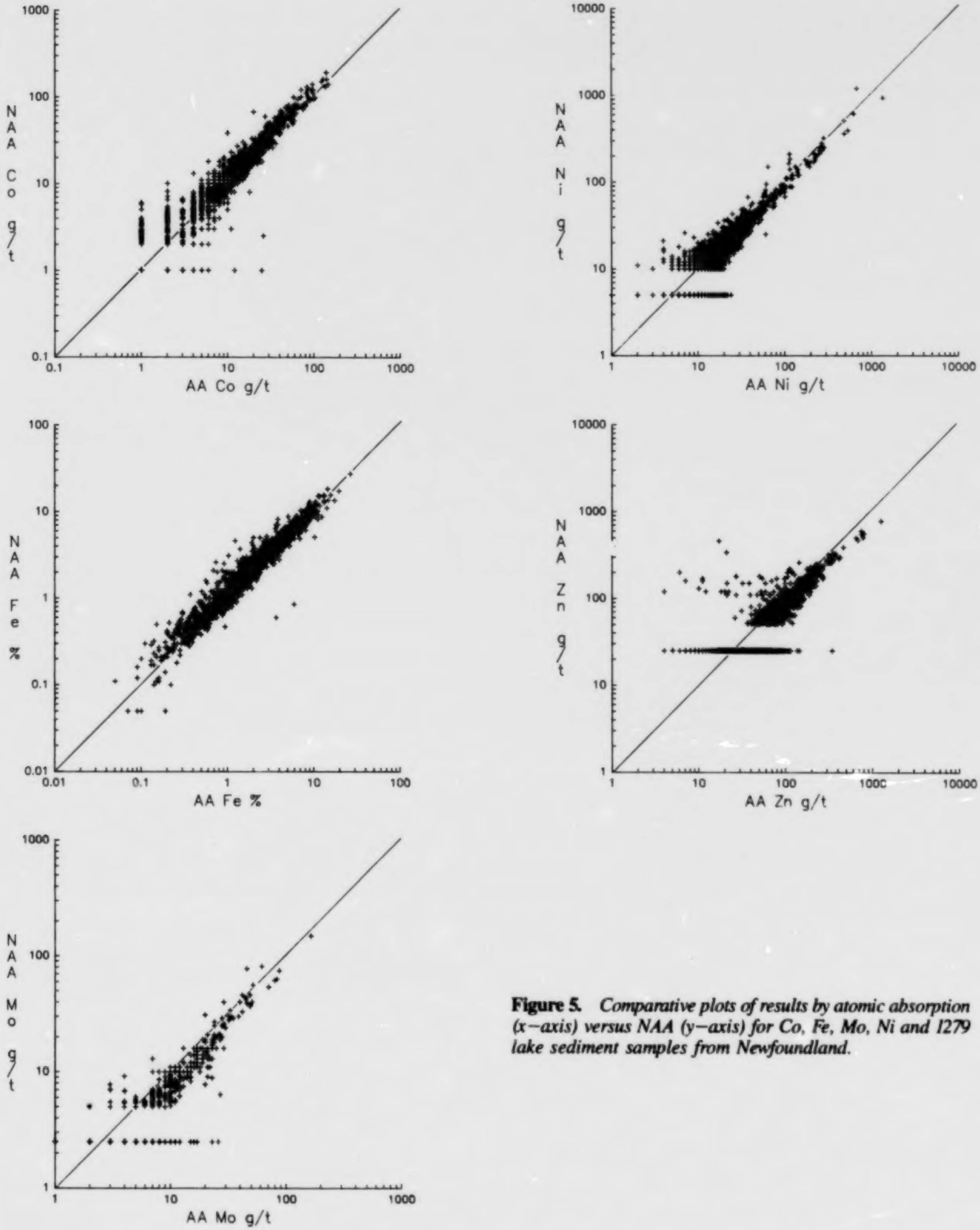


Figure 5. *Comparative plots of results by atomic absorption (x–axis) versus NAA (y–axis) for Co, Fe, Mo, Ni and I279 lake sediment samples from Newfoundland.*

Table 4. Comparison of multi-element NAA data for Ag, Co, Fe, Mo, Ni and Zn with results by atomic absorption for regional lake sediment samples. All data were log transformed.

Element	Number of samples	Correlation coefficient r	Regression equation (slope)	(intercept)
Ag	1279	0.036*	0.086	-0.760
Co	1279	0.926	0.857	0.094
Fe	1279	0.967	0.981	-0.052
Mo	1275	0.748	1.096	-0.042
Ni	1279	0.882	0.902	0.138
Zn	1279	0.754	0.815	0.377

* not significant ($p = 0.68$)

Analysis of Ba, Ce, La, Th and Zr by ICP Spectrometry

Replicate determinations of 101 lake sediment samples were performed by inductively coupled plasma (ICP) spectrometer for Ba, Ce, La, Th and Zr, following the digestion of 1 g of sample in an $HF-HClO_4-HNO_3$ acid mixture. The results are plotted in Figure 6, and the correlation coefficients, and slopes and intercepts of the regression equation from log-transformed data (NAA on ICP data) are given in Table 5. For Ce, La and Ba the correlations between the two methods are very good. For Th, the higher effective detection limit of ICP (approximately 5 g/t) and, for Zr, the relatively high detection by NAA (approximately 100 g/t), lead to considerable scatter at lower concentrations. The Ce, La and Ba data are satisfactory by either method, whereas Th is better by NAA and Zr by ICP.

Table 5. Comparison of multi-element NAA data for Ba, Ce, La, Th and Zr with results by ICP spectrometer for 101 lake sediment samples. All data were log transformed.

Element	Correlation coefficient r	Regression equation (slope)	(intercept)
Ba	0.979	1.073	-0.205
Ce	0.983	0.895	0.244
La	0.976	0.929	0.124
Th	0.753	0.365	0.769
Zr	0.844	0.890	0.601

EFFECT OF DOUBLE IRRADIATION ON NAA RESULTS

One of the advantages of NAA is that sample material is conserved, and can be used for further chemical analyses. The sample is altered, however, by the transmutation of a small proportion of the atoms into new radioactive isotopes during irradiation, which forms the basis of the analytical method. Some of these radioisotopes have half-lives of months or years, and although the proportions of new isotopes to their precursors are very small, a measurable amount of these radiation products with longer half-lives may be retained for months or years. If such irradiated material is subjected to a second irradiation and analysis, the products of the second irradiation will be added to those remaining from the initial irradiation, and the results will be erroneously high. Moreover, the amount of the enhancement will vary depending on the half-life of the isotope, the time between irradiations, and the neutron fluxes and exposure times in each case. In general, these parameters are not known by the person requesting the analysis.

This long-lasting effect is particularly important if a repeat NAA analysis is required on a sample, and all the material has been irradiated in the initial analysis. This effect also precludes the use of the same portion of standard reference material more than once to monitor analytical accuracy.

To gain an appreciation of the effect of double irradiation of material on the reported analytical results, samples that had been irradiated and analyzed at two laboratories were reanalyzed. Set A was analyzed by laboratory A in April 1986 and set B was analyzed by laboratory B in April 1987. Both sets were reanalyzed at laboratory B in August, 1987 (the same aliquot of material was re-irradiated and analyzed again). Set A samples (numbering 28) were typical lake sediments, and set B were control reference samples (17 lake sediment, 2 stream sediment). In Table 6, the means of the reported element content for singly and doubly irradiated samples are given, together with the probability that the paired values are, on average, different, using Student's 't' test for paired data. For set A, for almost all elements, the reported values for the doubly irradiated material are from slightly higher to very much higher than the 'true' values, as revealed by the singly irradiated set (the exceptions are Lu, Se, Ta, Yb). The 't' test results show that significant (i.e., $p < 0.05$) differences are shown by Au, Co, Cs, Eu, Ni, Sc and Zn, with the doubly irradiated values being from 1.2 to 15.7 times higher.

There is no general trend of increased levels of element values in the doubly irradiated material for set B, although Co, Cs, Eu, Sc and Zn are significantly higher (as they were in set A). In addition, La, Lu, Mo, Ta and Tb are also significantly higher in the doubly irradiated material in set B, but these elements showed no significant difference in Set A. Overall, the increases due to the double irradiation in set B (from 1.1 to 2.2 fold) are much lower than in set A (from 1.2 to 15.7 fold).

Since all the data in Table 6 were determined at the same laboratory in one analytical project, the observed differences between the values for doubly and singly irradiated samples in sets A and B must reflect their different irradiation histories. The irradiation used at laboratory B appears to have less of a lasting effect than that used for laboratory A. From

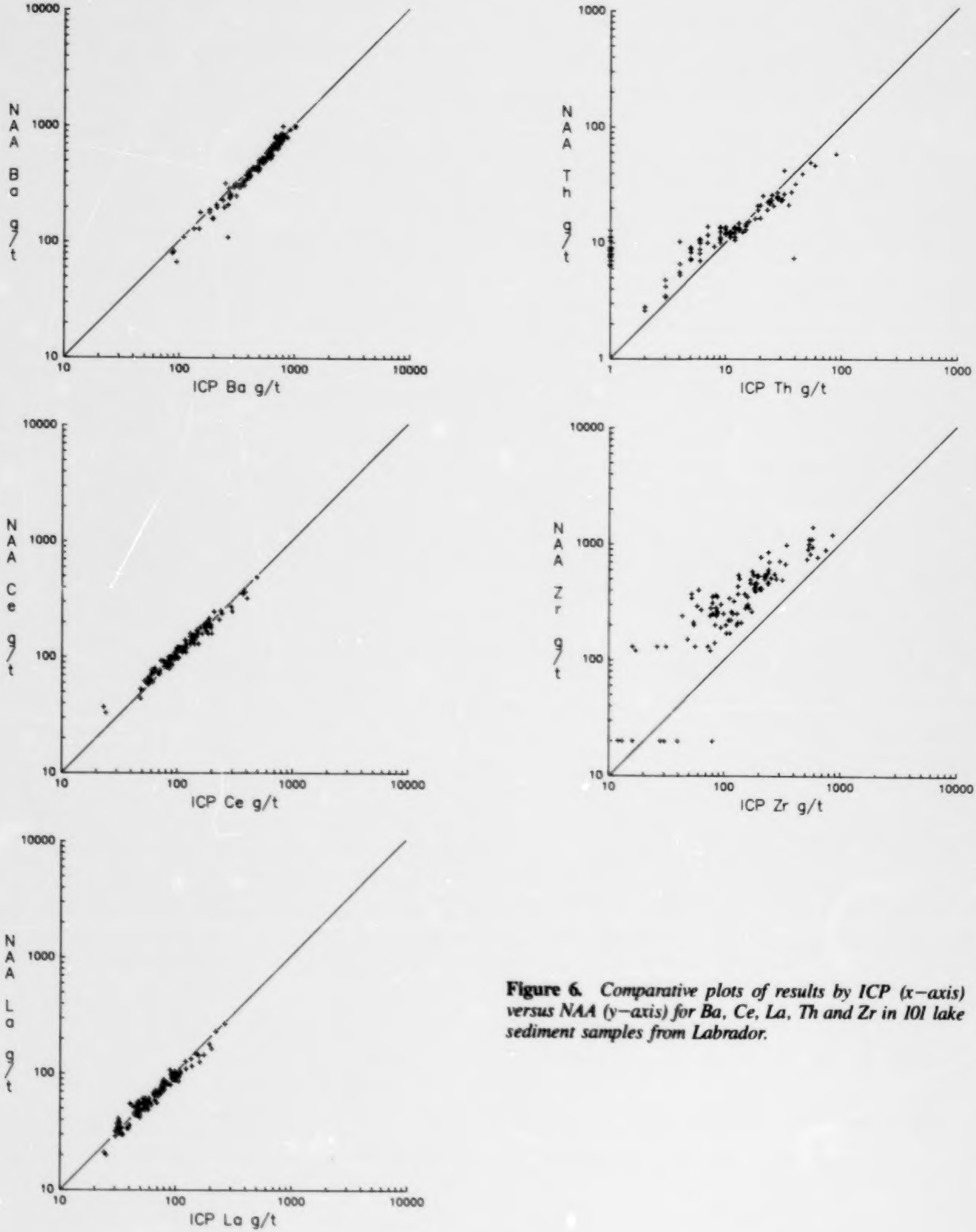


Figure 6. *Comparative plots of results by ICP (x−axis) versus NAA (y−axis) for Ba, Ce, La, Th and Zr in 101 lake sediment samples from Labrador.*

Table 6. The effect on reported results when material subjected to an initial multi-element NAA analysis is subjected to a second irradiation and neutron count.

		Set A Reanalysis of lake sediment samples			Set B Reanalysis of control samples		
Element	Unit	Mean 1	Mean 2	p(t)	Mean 1	Mean 2	p(t)
Au[1]	mg/t	1.62	2.69	0.007	1.58	1.08	0.444
As	g/t	3.33	3.59	0.300	16.9	16.2	0.466
Ba	g/t	177	193	0.090	675	755	0.598
Br	g/t	13.3	13.8	0.531	35.2	35.2	0.998
Ce	g/t	38.5	42.3	0.084	178	169	0.335
Co[2]	g/t	6.7	68.7	0.000	23.3	40.6	0.000
Cr	g/t	39.8	45.3	0.050	35.8	42.0	0.090
Cs[2]	g/t	1.37	3.66	0.000	2.48	4.80	0.000
Eu[2]	g/t	0.77	12.1	0.000	1.39	3.10	0.000
Fe	%	2.11	2.21	0.241	5.75	6.10	0.448
Hf	g/t	1.1	1.2	0.223	3.08	2.82	0.446
La[3]	g/t	36.8	41.1	0.223	57.5	63.1	0.023
Lu[3]	g/t	0.20	0.20	0.757	1.01	2.12	0.008
Mo[3]	g/t	3.62	3.89	0.276	9.8	12.7	0.021
Na	%	0.253	0.283	0.051	0.78	0.86	0.119
Ni[1]	g/t	31.1	37.0	0.013	15.9	10.6	0.075
Rb	g/t	24.3	25.7	0.126	38.8	36.4	0.555
Sb	g/t	0.33	0.42	0.081	0.83	0.80	0.604
Sc[2]	g/t	4.6	6.5	0.000	7.78	10.47	0.000
Se	g/t	1.15	1.13	0.919	1.81	1.55	0.596
Sm	g/t	4.65	4.86	0.390	9.07	9.07	1.000
Ta[3]	g/t	0.22	0.20	0.192	0.54	0.86	0.005
Tb[3]	g/t	0.49	0.50	0.600	1.87	2.42	0.032
Th	g/t	3.61	3.82	0.067	11.6	12.0	0.425
U	g/t	2.61	2.78	0.197	30.8	34.6	0.115
W	g/t	1.0	1.1	0.356	1.31	1.43	0.357
Yb	g/t	0.94	0.91	0.648	4.12	5.55	0.077
Zn[1]	g/t	140	467	0.000	198	356	0.005
Zr	g/t	105	151	0.062	175	230	0.489

NOTE: Set A is for 28 normal lake sediment samples, where Mean 1 represents the average for each element for pristine sample material for the element at lab B, whereas the Mean 2 column gives the average results reported by lab B on splits of the same samples which had been analyzed previously by NAA at lab A. Set B is for 19 control samples (17 lake sediment and 2 stream sediment) where again Mean 1 for each element is for pristine material, and Mean 2 is for doubly irradiated material, in this case with all sample irradiation conducted by lab B. The columns p(t) are the probability that the paired values for singly and doubly irradiated material are the same using Students 't' test for paired data. All results in this table were from lab B in the same analytical batch.

[1] significantly higher in twice-irradiated duplicate samples; first irradiation at N.A.S., second analysis by Becquerel.

[2] significantly higher in twice-irradiated control samples; both irradiations and analyses by Becquerel.

[3] significantly higher in both twice irradiated duplicate and control samples.

the data in Table 6, it is not clear whether the enhancements to La, Lu, Mo, Ta and Tb in set B would become negligible if the length of time between irradiations was the same as for set A (16 months rather than 4).

To determine whether the bias between singly and doubly irradiated samples in set A is sufficient to impair data interpretation, the doubly and singly irradiated data were compared using the Mann-Whitney U test (a nonparametric equivalent of Student's 't' test). Using this test, only Cs, Eu, Zn and Zr were significantly different (higher) in the doubly irradiated samples ($p < 0.05$).

These data show that in general sample material should not be sent for this type of multi-element neutron activation more than once, as for several elements the effect of the initial irradiation will lead to errors in several elements in the subsequent analysis. If it is absolutely necessary to reanalyze sample material by neutron activation a second time because of lack of additional sample material, a sufficient number of replicates of unirradiated material should be included to fully assess the effects of the initial irradiation. This will vary from one laboratory to another, and may even vary from the same lab if their irradiation procedures change.

DISCUSSION AND CONCLUSIONS

Multi-element NAA does provide good-quality analytical data for many elements in lake sediment. An overall assessment for all 35 elements determined in the suite discussed here is given in Table 7. The abundances of As, Ba, Br, Ce, Co, Cs, Fe, Hf, La, Lu, Rb, Sc, Sm, Ta, Tb, Th, U and Yb are determined satisfactorily by this method. For the elements Cr, Eu, Mo, Ni, Se, W, Zn and Zr, the detection limits are high enough to preclude their determination at the lower levels found in lake sediment. Nevertheless, the NAA data are useful in geochemical exploration. The detection limits for Ag, Cd, Hg, Ir, Sn and Te are too high to be useful.

The detection limit for Au by NAA (approximately 2 mg/t) is higher than the median Au content of lake sediment (<1 mg/t), and is therefore much higher than is desirable. There is, however, no obvious, cost-competitive alternative method that would offer significantly lower detection limits and be applicable to large sample sets. The method does seem to offer slightly better data than that acquired by graphite-furnace or atomic absorption. The absolute values for Au from both techniques compare well, and also from the more

Table 7. A summary of the data quality of multi-element neutron-activation analysis (NAA) for lake sediment samples from control reference samples and replicate analyses of sample splits.

	Quoted Detection Limit	Actual Detection Limit	Abundance in the Lake Sediment Analyzed		Assessment of Data Usefulness
			range	mean	
Au (mg/t)	1	2-3	<1-24	1.9	fair to poor; anomalous values (>4-5 ppb) can be quantified
Sb (g/t)	0.05	0.05	<0.05-1.9	0.21	fair; a lower real detection limit would improve the data
As (g/t)	0.2	0.5	<0.2-228	27	good
Ba (g/t)	20	50	<20-1200	219	good
Br (g/t)	1	1	1.8-161	49	good
Cd (g/t)	2	? 2	<2-9.1	-	poor; detection limit 10 times too high
Ce (g/t)	3	3	4.8-608	102	good
Co (g/t)	2	2	<2-140	17	good
Cs (g/t)	0.5	0.5	<0.5-12	1.6	good
Cr (g/t)	2	15	<2-393	47	fair; a lower detection limit would improve the data
Eu (g/t)	0.2	0.5	<0.2-5.3	1.2	fair; a lower detection limit would improve the data
Fe (%)	0.1	0.1 or lower	<0.1-15.6	3.1	good
Hf (g/t)	0.5	1	<0.5-23	2.7	good
Hg (g/t)	1	?	<1	-	useless; the detection limit is about 100 times too high
Ir (mg/t)	20	?	<20	-	useless; the detection limit is far too high
La (g/t)	1	1	5.7-304	44	good
Lu (g/t)	0.05	0.05	<0.05-3.5	0.4	good
Mo (g/t)	0.5	5	<0.5-264	8.4	fair; a lower real detection limit would improve the data
Ni (g/t)	5	10	<5-250	24	fair; a lower real detection limit would improve the data
Rb (g/t)	5	5	<5-170	27	good
Sm (g/t)	0.1	0.1	0.34-53	7.3	good; two noisy controls
Sc (g/t)	0.1	? 0.1	0.7-22.1	7.2	good
Se (g/t)	1	? 3-5	<1-6.5	1.2	poor; a lower detection limit would improve the data
Ag (g/t)	1	? 1	<0.2-3	-	useless; the detection limit is about 20 times too high
Na (%)	0.05	0.05	<0.05-4.00	0.62	good
Ta (g/t)	0.2	0.2-0.3	<0.2-3.5	0.41	good
Te (g/t)	10	?	<10	10	useless; the detection limit is far too high
Tb (g/t)	0.5	0.5	<0.5-9.3	1.1	good
Th (g/t)	0.1	0.1	0.68-41.5	7.6	good
Sn (g/t)	50	?	<50	-	useless; the detection limit is far too high
U (g/t)	0.1	0.1	<0.1-180	13.5	good
W (g/t)	0.5	2	<0.5-67.4	2.2	fair; anomalous values (>5 ppm) can be reproduced
Yb (g/t)	0.1	0.5	<0.1-27.3	2.1	good; precision falls off rapidly below 1 ppm
Zn (g/t)	50	75	<50-440	97	fair to good; detection limit a little high
Zr (g/t)	50	250	<50-1100	173	fair; real detection limit about 5 times too high

sensitive neutron-activation, fire-assay, neutron-counting methods. The information on analytical precision for Au from the control samples, analyses of sample splits by three laboratories, laboratory replicates and site duplicates (not discussed here) suggest that Au in lake sediment is quite homogeneous. In fact, the routine samples seem to be more homogeneous than some of the control reference materials in Au. This suggests that the Au is probably complexed with the organic material and is not generally present as a discrete metallic phase. Thus organic lake sediments would seem to be a very good sample medium for regional Au exploration.

The nondestructive nature of the direct NAA method is a great advantage, since it permits further chemical analysis of the sample material. Some long-lived isotopes are created during irradiation which will cause spuriously high results if the material is subjected to a second neutron activation analysis. In general, therefore, a portion of sample material should be analyzed only once by NAA.

Careful monitoring of analytical precision is necessary for Au because values of interest are so close to the detection limit of the method. The inclusion of sample splits is essential, and these should be chosen randomly from the sample set and included without disclosing their identity as duplicates. At least 30 pairs are required to give a good estimate of precision, although as few as 10 pairs in small sample batches will give a qualitative idea. The inclusion of site duplicates as well as sample splits is also strongly recommended to allow assessment of overall sample to sample variance.

ACKNOWLEDGMENTS

The multi-element NAA were carried out by Becquerel Laboratories Incorporated, Mississauga, Ontario, under the direction of Dr. Craig Stuart, whom I would like to thank for his help. The other NAA data for gold were provided by Nuclear Activation Services Limited, of Hamilton, Ontario, and the gold data by graphite furnace atomic absorption by Barringer-Magenta Limited; both companies are thanked for their work. The remaining analyses were carried out by the Department of Mines Laboratory, St. John's.

REFERENCES

Davenport, P.H. and Nolan, L.W.
1987: Gold and associated elements in lake sediment from regional surveys in the Port aux Basques area (NTS 11O) and the White Bay area (NTS 12H/9,10,11,15 and 16; 12I/1). Newfoundland Department of Mines, Mineral Development Division, Open File NFLD 1582.

Fletcher, W.K.
1981: Analytical methods in geochemical prospecting. Elsevier, Amsterdam, 255 pages.

Fletcher, W.K., Hoffman, S.J., Mehrtens, M.B., Sinclair, A.J. and Thomson, I.
1987: Exploration Geochemistry: design and interpretation of soil surveys, Chapter 4, Analysis of Soil Samples. Reviews in Economic Geology, Volume 3, Society of Economic Geologists.

McConnell, J.W.
1987: Gold and associated trace elements in Newfoundland lake sediment from four areas of known gold mineralization. Newfoundland Department of Mines, Mineral Development Division, Open File NFLD 1509.

Thompson, M. and Howarth, R.J.
1978: A new approach to the estimation of analytical precision. Journal of Geochemical Exploration, Volume 9, pages 23-30.

Wagenbauer, H.A., Riley, C.A. and Dawe, G.
1983: The geochemical laboratory. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 83-1, pages 133-137.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 415-435

GEOPHYSICAL INVESTIGATIONS AT WEIR'S POND, MOUNT SYLVESTER AND SNOWSHOE POND, NEWFOUNDLAND: IMPLICATIONS FOR LITHOLOGIC DISTRIBUTION AND STRUCTURE

Gerry Kilfoil
Geochemistry and Geophysics Section

ABSTRACT

Three areas in central Newfoundland were investigated by magnetic and VLF-EM.

A gap in the prominent aeromagnetic anomaly associated with magnetic units within the Gander River Ultrabasic Belt (GRUB) was the target of surveys in the Weir's Pond (2E/1) and Carmanville (2E/8) map areas. The geophysical signatures of rock units mapped in detail in the vicinity of Weir's Pond were used to trace similar units within the Carmanville map area. The absence of a strong aeromagnetic anomaly northeast of Weir's Pond is the result of a predominance of lower Davidsville Group clastic rocks north of an east-west fault. The occurrence of hydrothermally altered equivalents of the GRUB are relatively rare in this northern area. An attempt to trace the boundary between Gander Group and Davidsville Group rocks through this nonmagnetic area using the above geophysical methods proved unsuccessful.

In the Mount Sylvester (2D/6) map area, a northeast-orientated, structural linear, defined by sporadic outcrops of chromite-bearing ultramafic rocks and associated lenticular aeromagnetic anomalies, was investigated by several ground traverses. Results of modelling on the asymmetrical magnetic anomalies indicates that the ultramafic bodies dip to the southeast at angles ranging from 55 to 75°. Spatial relationships of anomalies suggest that the linear in the Mount Sylvester area is defined by several small prismatic ultramafic bodies arranged en echelon *in fault contact with the siliciclastic rocks of the North Steady Pond Formation to the northwest.*

Two shear zones within units of the Victoria Lake Group were investigated by surveys south of Lake Douglas in the Snowshoe Pond (12A/7) map area. The shear zones showed little character in the magnetic or VLF-EM data. However, a north-northeast-oriented zone within deformed clastic rocks showed a strong magnetic and conductive signature on several traverses, suggesting a structural repetition of the unit. A magnetically anomalous zone was also identified within a unit mapped as mafic volcanic rocks. A highly deformed pelitic layer separating mafic volcanic rocks from volcanogenic sediments was traced by its anomalous conductivity. Several other mapped units were also characterized geophyscially.

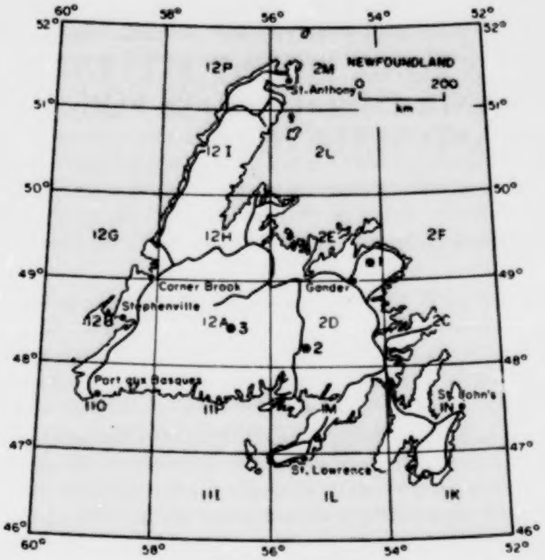
INTRODUCTION

Geophysical surveys were carried out in areas of central Newfoundland during the 1987 field season (Figure 1) to provide a more continuous picture of bedrock geology in regions of little or no bedrock exposure, and to elucidate geological structures. Some of these structures, especially those faults containing ultramafic rocks in the Weir's Pond and Mount Sylvester areas, may be important as loci of gold mineralization (Tuach *et al.*, *this volume;* Tuach, 1987a,b).

Survey Instrumentation and Procedures

Values of the total magnetic field were measured initially by an OMNI IV (EDA Instruments). Measured values were corrected for diurnal variations using a reference of total field values recorded on a 30-second interval by another OMNI IV operating in the base station mode. The inphase and quadrature (out-of-phase) responses of the VLF field were measured by an EM-16 (Geonics) receiver by audibly nulling the received signal by varying the tilt angles and quadrature dial adjustments. The OMNI IV field unit was subsequently replaced by an OMNI Plus instrument, which has capabilities of simultaneous measurement of as many as 3 VLF signals in addition to the magnetic field, and recording both VLF and magnetic readings digitally in internal memory. This allowed the signal from Annapolis, Maryland to be recorded in addition to that from Cutler, Maine. These two transmitters were the only two with sufficient signal strength for surveying in insular Newfoundland. For 10 survey days the survey procedures overlapped: both the EM-16 and OMNI Plus receivers were used for measurement of the local VLF field to facilitate correlation and calibration. Later comparison of the received signals (24.0 kHz) from the two instruments showed an extremely good correlation.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989



INDEX MAP

Figure 1. *Study area locations.*

Survey lines were oriented generally at azimuths of 135 to 140°; offsets were introduced to avoid bodies of water or otherwise impassable terrain. A 10-m station spacing was adopted after the first few profiles to obtain the detail necessary for an accurate representation of the VLF field. The southeast profile orientation was chosen to be nearly perpendicular to both the general northeasterly structural trends in the study areas and the incoming VLF signals transmitted from Cutler, Maine (24.0 kHz) and Annapolis, Maryland (21.4 kHz). This arrangement provides optimum inductive coupling to conductors. Traverses were concentrated in areas showing the largest geophysical response.

The data are presented on survey location maps with the magnitude of anomaly plotted vertically above the position along the traverse where the value was recorded. Thus, the location of an anomaly is that point along the traverse vertically beneath the peak, and the magnitude of the anomaly is the scaled offset from profile point to peak. The desired result of this display method is to have the anomalous field appear to stand out of the page in an attempted three dimensionality. A major disadvantage is that, where the anomalous field is large and variable and where profiles are closely spaced, the profiles tend to overlap in nonaesthetic confusion. Contours of a potential field, on the other hand, do not intersect. It is felt that data are better displayed in profile form on these maps, rather than using contours, for the following reasons:

1) averaging and smoothing is introduced by the gridding used to produce contours, therefore much of the high-frequency content used to estimate depth to source is eliminated from contour maps, and

2) since locations, relative magnitudes and shapes of anomalous features are displayed by profile plots, any offset errors present, particularly in magnetic data, become less prominent between adjacent profiles.

Values of the magnetic field are displayed on profile location maps with mapped geology and limited topography included as reference. The VLF−EM field is displayed on similar maps in the form of profiles of the Fraser filtered, inphase response (Fraser, 1969, 1981). The Fraser filter values were chosen for display since the filter provides a limited smoothing and the resultant values represent the digital first derivative of the inphase response (Fraser, 1969). In this way, maximum negative slopes on the inphase profile, which indicate conductivity, result in positive peaks on the Fraser filter profiles. Typical VLF and magnetic profiles or those containing features of interest are also included as side-by-side plots for correlation purposes. It should be noted that the scale of anomaly differs from profile to profile depending on the range of values in each profile.

WEIR'S POND

Objectives

The prime objective in the Weir's Pond (2E/1) map area was to determine the cause for the abrupt northern termination of a large aeromagnetic anomaly associated with Gander River Ultrabasic Belt (GRUB) rocks near the Weir's Pond−Carmanville map area boundary (Geological Survey of Canada, 1969a,b; Rockel, 1973). A secondary objective was to investigate the geophysical signature and orientation of a reported conformable contact (Currie and Pajari, 1977; Currie, *et al.*, 1980a,b) of the Gander and Davidsville groups within the nonmagnetic section of the GRUB northeast of Weir's Pond.

Geology and Previous Work

The principal geologic elements of the area are the Gander Group, GRUB and Davidsville Group; their relationships are described elsewhere (O'Neill, 1987; Blackwood 1980, 1982; Currie and Pajari, 1977). The GRUB succession in the vicinity of Weir's Pond consists of (O'Neill, 1987, 1986a,b):

1) an ultrabasic unit, variably altered to magnesite talc, and serpentinite,

2) gabbroic rocks,

3) mafic volcanic rocks, and

4) trondhjemite

Numerous faults, identified or inferred from geological exposures (O'Neill, 1986a), have structurally repeated the GRUB succession.

Clastic sedimentary rocks of the Davidsville Group, ranging from immature sandstone and conglomerate at the base to largely more mature siltstones and sandstones in the upper parts, are structurally imbricated with the ultrabasic belt and overlie the belt to the northwest. The pelites and semipelites of the Gander Group show increasing metamorphic grade to the east in the Weir's Pond map area. The contact between the ultramafic rocks and the Gander Group is nowhere exposed in the Weir's Pond area. Exposures of ultramafic rocks of the GRUB west of Weir's Pond exhibit varying alteration (O'Neill, 1987).

The Weir's Pond and Carmanville map areas have been covered by an aeromagnetic survey flown at a 300-m altitude and 0.8-km flight line spacing (Geological Survey of Canada, 1969a,b). An airborne electromagnetic- and magnetic-survey was flown over the northern part of the GRUB as reported by Rockel (1973). Several geophysically interesting features identified from these surveys were later followed up on the ground (Zurowski, 1974a,b).

Access and Topography

Access to the northern part of the Weir's Pond area from the Gander Bay highway was provided by a network of logging roads in good condition. Access in the Carmanville map area was also by a system of woods roads, in disrepair, off Route 330 from Carmanville. Temporary field camps were established along woods roads and surveys were conducted within walking distances of overgrown trails. Helicopter support was required on one occasion to provide access to a remote survey location.

Extensive bogs, numerous ponds, wooded, gently rolling hills and small outcrop ridges cover the area. Surface features strongly reflect the northeasterly bedrock trend. Much of the region east of Weir's Pond was burned over and is now heavily vegetated by second-growth thicket, markedly hampering survey progress.

Interpretation of Magnetic and VLF–EM Data

Geophysical traverses were positioned over units of the GRUB with the emphasis on the contact with the Gander Group. Profiles were oriented at 140° where topographic features would permit. Figure 2 shows a profile location plot for traverses north and east of Weir's Pond. The magnetic profiles are total field values with the long wavelength field of the International Geomagnetic Reference Field (IGRF) (Peddie, 1986) removed. In addition, a constant field value of 600 nT was added so that low magnetic background levels, such as the variable field observed in Gander Group sedimentary rocks, would plot near the zero level. Thus the IGRF level is not representative of the background field in the Weir's Pond area. The observed low background levels agree with those recorded at the 300-m altitude, published as 1:1,000,000 scale maps (Geological Survey of Canada, 1984a,b), throughout Newfoundland's Central Mobile Belt. Here, these maps show values lower than the IGRF by 300 to 1000 nT.

Magnetic signatures show a strong correlation with mapped rocks types in the Weir's Pond area (lower portion) of Figure 2. The ultramafic rocks (Unit 2) and the mafic volcanic rocks (Unit 4) are responsible for the largest and most variable anomalies displayed. A low and variable magnetic field was recorded over a large area underlain by gabbroic rocks near the southwest shore of Weir's Pond (near 689E,5454N). A narrow, low magnitude anomalous zone, recorded on the two parallel lines here, provides evidence that the gabbro is bisected. This anomaly may be due to a break between two phases of gabbro emplacement or a structural repetition of gabbro with an intervening stringer of mafic volcanic rocks. The lower Davidsville Group of Unit 6 correlates everywhere with low uniform magnetic fields. On the basis of magnetic signatures, the positioning of lithologic contacts, as mapped by O'Neill (1987) in the vicinity of Weir's Pond, require very little adjustment.

Although modelling of magnetic profiles from Weir's Pond has not been completed, the relative magnitudes of lows associated with the larger magnetic highs suggest a near vertically oriented structure. This is in general agreement with orientation data measured on outcrop.

One of the more prominent and laterally continuous features on Figure 2 is a sharp magnetic anomaly at the contact of the ultrabasic belt of the GRUB with the Gander Group. Correlation of adjacent peaks shows a strong northeasterly trend, but with minor offsets. The peaks should lie vertically above the centres of their causative rock units, whereas locations of the bounding fault should lie 40 to 60 m to the southeast. Apparent offsets in the contact position are thought to be partially the result of offsets along the many faults mapped within the GRUB units and partially due to lateral lithologic changes. The southeasternmost magnetic peak or 'basal anomaly' is caused by ultrabasic rocks (note anomaly magnitudes and profile scale) in the area immediately northeast of Weir's Pond, as evidenced by outcrop on Line 1700. An earlier ground survey reported by Zurowski (1974a,b) also detected offsets in the basal anomaly location. Farther to the northeast, near Cluff's Pond, rocks display increasing alteration, such that the basal magnetic unit here is probably a serpentinite. The prominent basal anomaly detected on Line 2300 is positioned on the northwest flank of a large magnesite outcrop (which has no magnetic signature), suggesting that the actual GRUB–Gander contact is southeast of the basal magnetic anomalies. Thus the most magnetic rocks do not always comprise the basal GRUB outcrops, and their relative positioning may explain many apparent small offsets in the basal anomaly trend.

Many of the magnetic features on Figure 2 reflect the underlying northeast trend of the basal anomaly. Several other features show overprinting of more easterly trends (slightly oblique to the basal anomaly), such as that defined by anomaly alignment on the northwest end of the northernmost profiles. Other northerly oriented trends evident on the anomaly map coincide with faults inferred from map patterns and lineaments (O'Neill, 1986a,b).

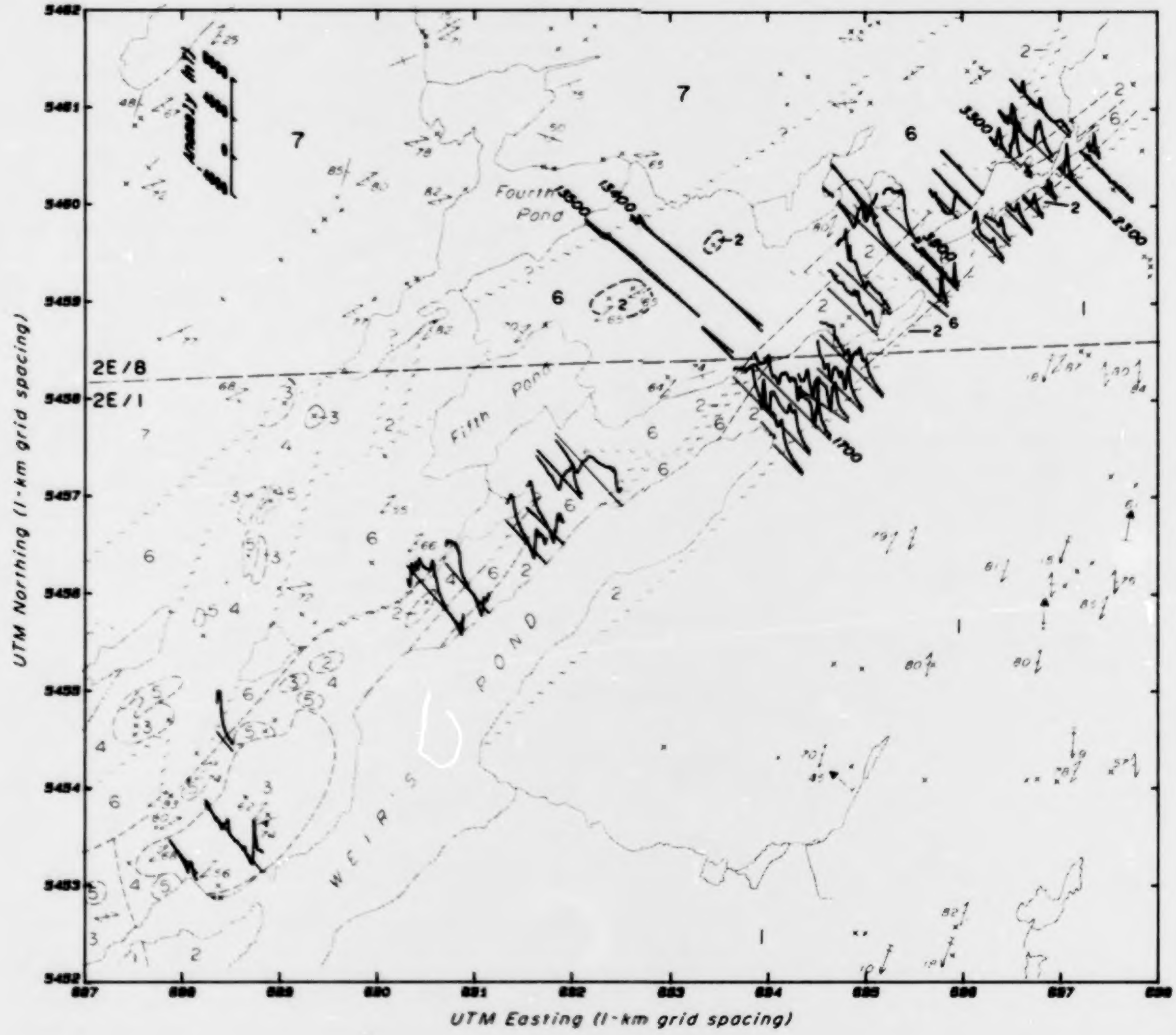


Figure 2. *Locations of total field magnetic profiles in the Weir's Pond (2E/1) and Carmanville (2E/8) map areas. Dashed line trending east-west separates the two map areas. Consult magnetic anomaly scale in the northwest corner of map for magnitude of anomaly relative to position along traverse. Geology from Currie* et al., *(1980b) (for 12E/8) and from O'Neill (1986b) (for 12E/1); a few modifications to geology for both map areas are based on interpretation of geophysical data acquired in this study. All map units, map unit numbers and map unit descriptions from O'Neill (1986b). Coordinates used here and in later figures are Universal Transverse Mercator (UTM) with a 1-km spacing.*

To the northwest, the low uniform magnetic field recorded on Lines 13400 and 13500 (Figure 2) is indicative of clastic rocks of the lower Davidsville Group. The magnetic field measured along Line 13400 is displayed in Figure 3 along with the inphase and quadrature components of the received VLF field. Calculated values of the Fraser filtered inphase response are included to correlate positions of conductive horizons.

Based on lower magnetic levels to the northwest, the small magnetic anomaly on Line 13400 (location -1140 m; Figures 2 and 3) marks the transition from immature siltstones and red shales comprising the lower parts of the Davidsville Group (Unit 6) into black siltstones and shale (Unit 7) of its upper part (Currie *et al.*, 1980b). Although the contact is displayed as a fault on Figure 2, the absence of a corresponding strong conductive anomaly suggests a conformable contact. The black siltstones of Unit 7, although containing clasts of GRUB units (Currie *et al.*, 1980b), are of lower magnetic susceptibility than the underlying red shales and deformed siltstones of Unit 6. The minor anomaly observed is that expected over the northwestern edge of a wide, uniformly magnetized block in these high magnetic latitudes and north-northwest declination.

LEGEND (Figure 2)

MIDDLE ORDOVICIAN

Davidsville Group

7 Upper Member: *grey to grey-green, rarely purple, siltstone; minor thin sandy beds and conglomerate*

6 Lower Member: *interbedded laminated siltstone; immature sandstone–locally crossbedded, fossil-rich sandstone; bioclastic limestone; calcarenite; graphitic black shale and polymictic boulder, cobble and pebble conglomerate*

MIDDLE ORDOVICIAN OR OLDER

5 *Aphanitic to coarse grained trondhjemite*

4 *Mafic volcanic and volcaniclastic rocks*

3 *Gabbro*

2 *Ultramafic rocks*

ORDOVICIAN OR OLDER

Gander Group

1 *Pelite; semipelite; quartzofeldspathic psammite; minor quartz granule sandstone; felsic and mafic sills and/or dykes*

SYMBOLS

——— *Geological boundary (approximate)*
Bedding, tops known (inclined, overturned)
Bedding, tops unknown (vertical)
Schistosity (inclined, vertical)
Mineralogical layering in gabbro
Fold axis (F_1, F_2)
Linear fabric (L_2)
‐ ‐ ‐ *Inferred fault (?-uncertain)*
× *Outcrop*

Minor variations in magnetic field between locations -1140 and -150 m on Line 13400 can be correlated with positions of conductive peaks in the VLF profile. This region is interpreted as underlain by the red shales of the Davidsville Group. The region from -150 to 480 m shows a smooth southeastward decrease in magnetic field and a corresponding lack of conductivity, and reflects the presence of the deformed black and white siltstones forming the basal unit of the Davidsville Group (Currie *et al.*, 1980b). Parallel Line 13500 shows excellent correspondence of features, particularly in midsection conductivity, indicating that these geophysical signatures are not topographically induced. Magnetic profiles of Lines 13400 and 13500 are subdued in their middle regions, suggesting an absence of a continuous ultramafic body as depicted by Currie *et al.* (1980b).

An anomaly prominent on several traverses near UTM coordinates 695E,5460N (Figure 2) exists over a till-covered, low topographic ridge of uncertain rock type. At the southwestern end of the ridge, ultramafic rock, altered to magnesite and ankerite, is exposed. Magnetic anomalies in profiles across the ridge increase in magnitude to the northeast, indicating increasing magnetic mineral contents, which are due to lenses of serpentinite or other highly magnetic ultramafic rocks in subcrop. These lower GRUB units are flanked to the northwest by lower parts of the Davidsville Group, as shown by a transition to low, smooth magnetic field values. The associated anomaly appears to terminate immediately north of Line 3800 (Figure 2; also Rockel, 1973), perhaps due to an east-southeast-oriented fault.

The several anomalies detected on the northernmost lines are interpreted to be caused by the presence of lenticular serpentinite pods, either in outcrop or shallow subcrop, aligned on fault trends. One such serpentinite body, not previously mapped, is exposed in a bog just north of Line 3300. Extremely variable anomalies, on the order of 1000's of nT, recorded directly over the outcrop, are indicative of anomalously large, probably zoned magnetite concentrations.

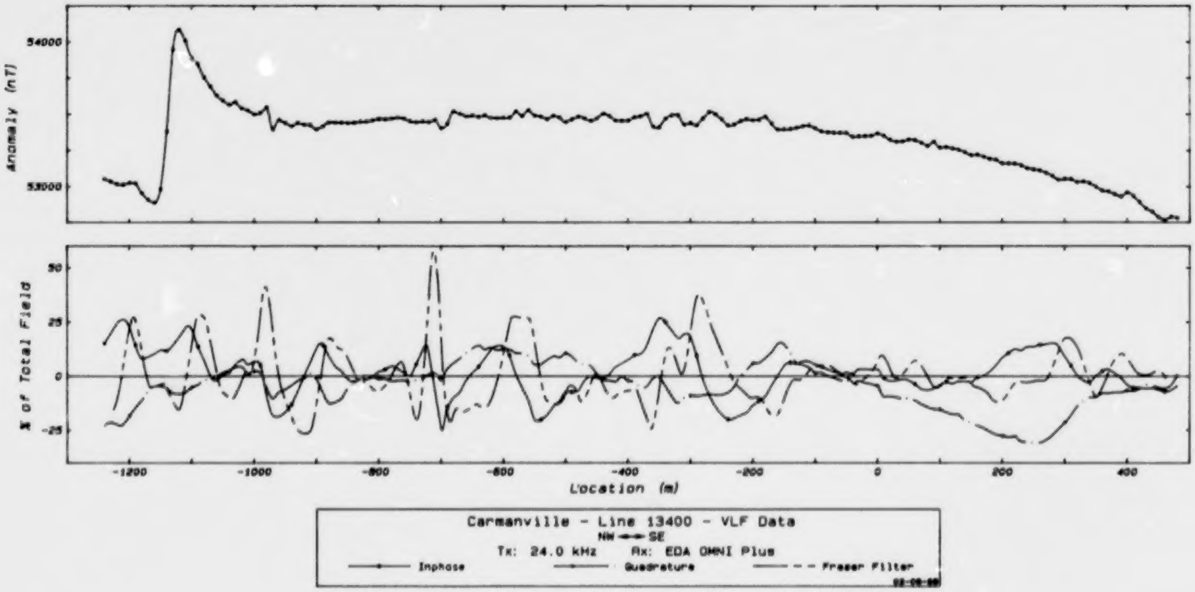


Figure 3. *Magnetic (upper) and VLF–EM (lower) profile data recorded along line 13400, Carmanville map area. See Figure 2 for location.*

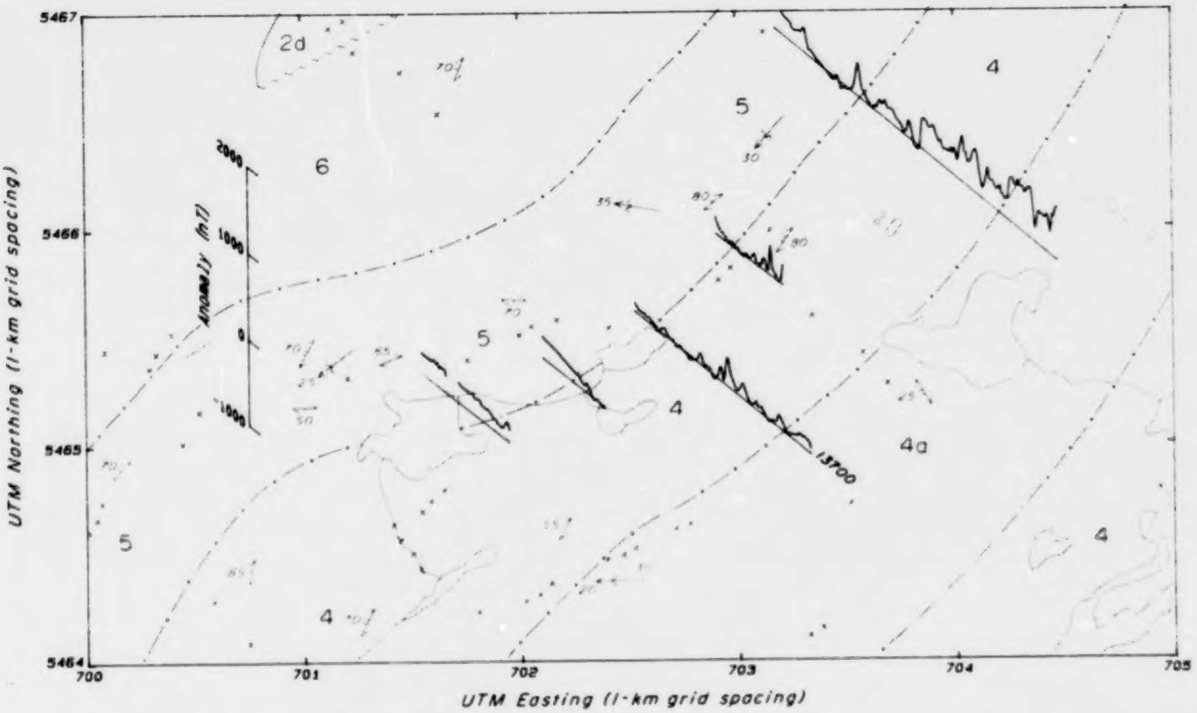
The northwestern margin of anomalous high magnetic values associated with the ultramafic rocks underlying Weir's Pond are detected on the southwest ends of profiles near coordinates 691E,5456N (Figure 2). A graphitic shale is responsible for the low magnetic values recorded between these anomalies and the magnetic highs detected to the northwest. The magnetic anomalies detected on the northwest ends of these lines are due to mafic volcanic rocks as inferred from the several mapped exposures (O'Neill, 1986a). This provides evidence for structural repetition of GRUB units. Structurally interleaved ultrabasic and gabbroic rocks cause the large variable anomalies observed just north of Weir's Pond, an area of extensive bog and till-covered ridges with little outcrop.

The controversial contact between the Davidsville and Gander groups north of Weir's Pond was investigated with several profiles traversing the mapped contact. Figure 4 is a map showing the locations of magnetic profiles. The boundary is not marked in this area by a strongly anomalous magnetic body (cf. anomaly scale with that of Figure 2). Approximate locations of a northwestward increase in magnetic levels follows the curvilinear northeastward trends in mapped lithology (Currie *et al.*, 1980b). Figure 5 shows the magnetic and VLF profiles for Line 13700. The VLF profile shows a strong conductor near the boundary position and a few weak conductors in the contact vicinity, possibly indicating the presence of several minor parallel faults. On adjacent lines, however, only weak conductors were detected. The contact location is not obvious on the basis of magnetic or VLF-EM values recorded from these traverses. Subtle differences in rock properties between the units on either side and a structural interleaving of the units (Piasecki, this volume) near the supposed contact create an environment that is not amenable to solution using these geophysical methods. The above findings concur with a recent megashear description of the contact zone, where deformation encompasses a 1-km- wide zone (Piasecki, *this volume).*

A highly variable magnetic field is observed within the Gander Group on the eastern most profile, Line 13900. The southeast end of Line 13900 approaches a north-trending belt of elevated aeromagnetic anomalies (Geological Survey of Canada, 1970) located entirely within Gander Group units. The northerly strike of this anomalous zone, which contrasts with the northeast strike of the GRUB or Davidsville Group, is parallel to a regional foliation in the Gander Group. The trend of the aeromagnetic anomaly intersects that of the GRUB northeast of the surveyed area. The source of this anomaly is uncertain, but may be related to a second ultrabasic belt as suggested by several exposures of mafic to ultramafic rocks on its eastern edge (recently mapped by O'Neill, *this volume).* The Gander Group magnetic anomaly deserves further geophysical investigations.

Conclusions

GRUB units in the Carmanville area generally possess a lesser magnetic response than units comprising the GRUB in the Weir's Pond map area (Geological Survey of Canada, 1969a,b). This is due to a combination of a northeastward increase in alteration and the fact that mafic and ultramafic rocks of the GRUB are less voluminous north of an interpreted east-west fault in the Carmanville map area. Exposures in the southern Carmanville map area, along strike with strongly magnetic ultramafic rocks north of Weir's Pond, are primarily magnesite–ankerite, serpentinite and deformed clastic rocks of the lower Davidsville Group.


5467
5466
5465
5464
700
701
702
703
704
705
UTM Easting (1-km grid spacing)
UTM Northing (1-km grid spacing)
Anomaly (nT)
2000
1000
0
-1000
2d
6
5
5
5
4
4
4
4
4a
13700
70
30
35
80
80
70
25
65
50
70
85
15
20
35
70
25

LEGEND

MIDDLE TO UPPER ORDOVICIAN

Davidsville Group

6 *Granule and conglomerate lenses containing volcanic and ultramafic clasts in grey-black siltstone and shale*

5 *Red shale exhibiting local grey-green bleached areas, and local limestone beds; basal sequence of thin-bedded black and white siltstone*

Gander Group

4 *Uniform thin-bedded, grey-green siltstone and quartz wacke; minor pelitic interbeds and conglomerate lenses; 4a, green volcanogenic schist containing amphibolitic layers and dykes*

MIDDLE ORDOVICIAN? AND OLDER

Gander River Ultrabasic Belt

2d *Rubble of volcanic and ultramafic rocks, probably gradational into Unit 6*

SYMBOLS

Vertical bedding

Inclined schistosity

Second-generation, inclined schistosity

Small-scale fold (arrow indicates plunge, inclination of axial plane known, unknown)

Figure 4. *Locations and magnetic results for traverses investigating the boundary between Gander Group (Unit 4 and subunit 4a) and Davidsville Group (Units 5 and 6, subunit 2d) in the Carmanville map area, northeast of Fourth Pond. Note expanded anomaly magnitude scale as compared to Figure 2. Geology and map unit numbers after Currie* et al., *(1980b).*

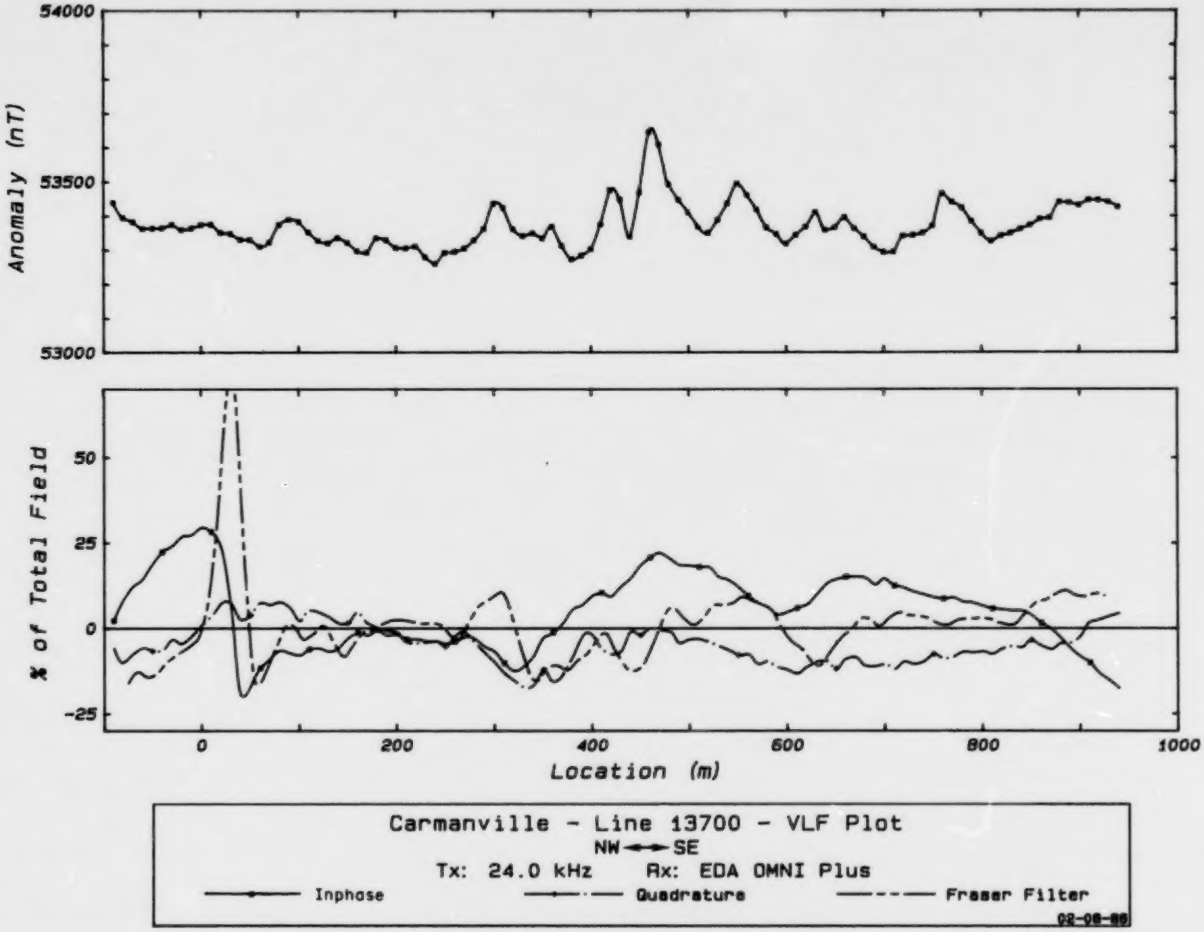


Figure 5. *Magnetic and VLF–EM profile data recorded along line 13700, Carmanville map area. See Figure 4 for location.*

Lack of consistent, correlatable geophysical anomalies near the Davidsville–Gander group boundary, south of Island Pond in the Carmanville area, indicates that mafic or ultramafic rocks of the GRUB are absent in the near surface. Units on either side of the boundary do not show strikingly different magnetic or VLF–EM responses. The presence of a conductor (at 0 m, Figure 5) near the transition could be interpreted as a strike-parallel fault or thrust, in agreement with the observation of Piasecki *(this volume)* that the rocks there are highly strained and locally mylonitic. The geophysical methods employed do not allow further discrimination between a conformable or structural contact.

MOUNT SYLVESTER

Objectives

The feature of interest in the Mount Sylvester map area, targeted for geophysical follow-up, is a series of small outcrops of chromite-bearing ultramafic rocks (Dickson, 1986, 1987). The objective was to determine the areal extent of ultramafic outcrops (or subcrops) and determine their subsurface orientation and relationship to enclosing sedimentary rocks.

Geology and Previous Work

The ultramafic outcrops in the Mount Sylvester map area trend northeastward from east of Conne River Pond to Middle Ridge in the Great Gull Lake map area (Dickson, 1986; Blackwood, 1983). Similar ultramafic rocks have defined linears related to thrust faulting elsewhere in Newfoundland (Colman-Sadd and Swinden, 1984), whereas this linear is described as part of an extensive shear-thrust zone (Dickson, 1987). The ultramafic rocks coincide with a linear magnetic anomaly, which is easily distinguished on aeromagnetic maps (Geological Survey of Canada, 1968a,b; McPhar Geophysics Limited, 1969) by its isolated highs within the relatively nonmagnetic surrounding units of the Baie d'Espoir Group. The surrounding rocks consist of sandstones and siltstones of the North Steady Pond Formation to the northwest, and pyritic and graphitic shales and siltstones of the St. Joseph's Cove Formation to the southeast.

Access and Topography

In the Mount Sylvester map area, geophysical surveys were carried out mainly from fly camps (see Figure 6 for profile locations), but the westernmost profiles were carried out from the Bay d'Espoir highway. The topography consists of large open-bog areas with uniform and gentle southeastward slopes and tree-covered drumlinoids. The entire area was burned over by forest fires in 1984.

Traverses were orientated at 140° to enable good coupling with VLF transmitters and to intersect, perpendicularly, the northeasterly trend of the ultramafic outcrops. Profiles range in length from 0.5 to 4.5 km. Most profiles bracket the ultramafic bodies by extension of traverses well into areas underlain by units to either side of the ultramafic rocks. Traverses were chosen and offsets were introduced where necessary to maximize survey coverage.

Interpretation of Magnetic Data

Figure 6 shows traverse locations with profiles of residual magnetic data (subsequent to IGRF removal) added for correlation between lines. Anomalies of largest amplitude and possessing the highest frequency components are those collected over outcrops of ultramafic rocks. At about UTM position (621E,5340N), where anomalies of high frequency component were observed but no outcrop exists, ultramafic rocks are suspected to occur at shallow depth. The asymmetric nature of the anomalies results from a combination of the high magnetic latitude (magnetic inclination = 70.4°), profile orientation, and the geometry of causative bodies in the subsurface.

To determine subsurface geometry, the magnetic profile for Line 4900 was modelled as a two-dimensional body with the cross-section as depicted in Figure 7. A strike of 045°, roughly that of the ultramafic outcrop trend, was assumed for the body during modelling. Line 4900 was selected for interpretation on the basis of its single, smooth anomaly. The anomaly breadth and degree of smoothness are indicative of a body buried to sufficient depth so that the effect due to any internal variation in magnetic mineral content is smoothed. In modelling the profile, it was observed that the dip angle of the body was tightly constrained ($\pm 1°$) by anomaly shape. Combinations of other parameters such as body width, magnetic susceptibility and depth could be modelled to produce similar fits with only slightly increased standard deviation. The 'error bars' associated with modelling these parameters are much wider. The model selected is considered to be a realistic representation of true body geometry, but the actual body shape may differ from that depicted in Figure 7 due to the following:

1) the body is modelled as a prism, having uniform thickness and dip, but the actual body would likely be variable in thickness and tend to sole out at depth;

2) a uniform susceptibility is assumed, whereas outcrops show variations and layering of magnetic mineral content (see other profiles on Figure 6); and

3) the magnetic anomaly due to the body is assumed to be entirely induced. The body is assumed not to possess remnant magnetization.

Several other profiles showing more complex or multiple anomalies (Figure 6) would require modelling with structures of increased complexity, particularly for profiles over near-surface subcrop or outcrop. Line 4900 was chosen to avoid such complexity and therefore obtain a realistic estimate of orientation and geometry. Other profiles indicate bodies having varying orientations, but generally dips are toward the southeast. The asymmetry of the profiles is dependent on attitude; strongly asymmetric profiles indicate shallower dips.

The northwest edge of the large magnetic anomalies has been correlated by crossover picks on Figure 6, and is informally called the ultramafic front. This anomalous magnetic front can be observed on all but the southwesternmost traverses, where the front appears to bifurcate and diminish rapidly in magnitude. By correlating adjacent peaks at the ultramafic front, a series of shorter arcuate fronts is defined (see Figure 6). These short fronts are manifested as double peaks on certain profiles and as two separate singular anomalies on others, depending on their mutual proximity. Offsets along the ultramafic front are most apparent where adjacent anomalies are displaced by discernible amounts. The individual ultramafic fronts generally possess a more northward orientation than the regional trend defined by the belt of ultramafic rocks. The ultramafic front is interpreted to be a series of *en echelon* arcuate ultramafic slices, which collectively create the gross appearance of a single thrust front.

A model of the ultramafic rock body and thrust sheet orientations is illustrated in Figure 8 (diagram not to scale). The thrust sheets would not likely be as uniform in thickness or orientation as depicted, but the concept provides an explanation of the sporadic nature of ultramafics along the thrust front. As well, variations in determined orientations of ultramafic bodies within the front from shallow- to steep-southeastward dips can be accommodated by this model. The truncated thrust sheets concept draws further support from the fact that, in general, the ultramafic outcrops are located at the northern termini of individual fronts (see Figure 6).

Near the southwest end of the survey, a similar but weaker front is observed approximately 2 km to the southeast of the ultramafic front, between UTM locations (617.5E,5336.3N) and (620.0E,5338.2N) (Figure 6). This may represent a second, similar imbricate-thrust zone in which ultramafic rocks do not reach the surface.

Interpretation of VLF-EM Data

Attempts to correlate similar trends over large distances between profiles of the Fraser filtered values from the VLF data were less successful due to the coalescing and bifurcating nature of many of the numerous EM anomalies (Figure 9). Several generalizations, however, can be made from the data. Although surface features have added noise to the received

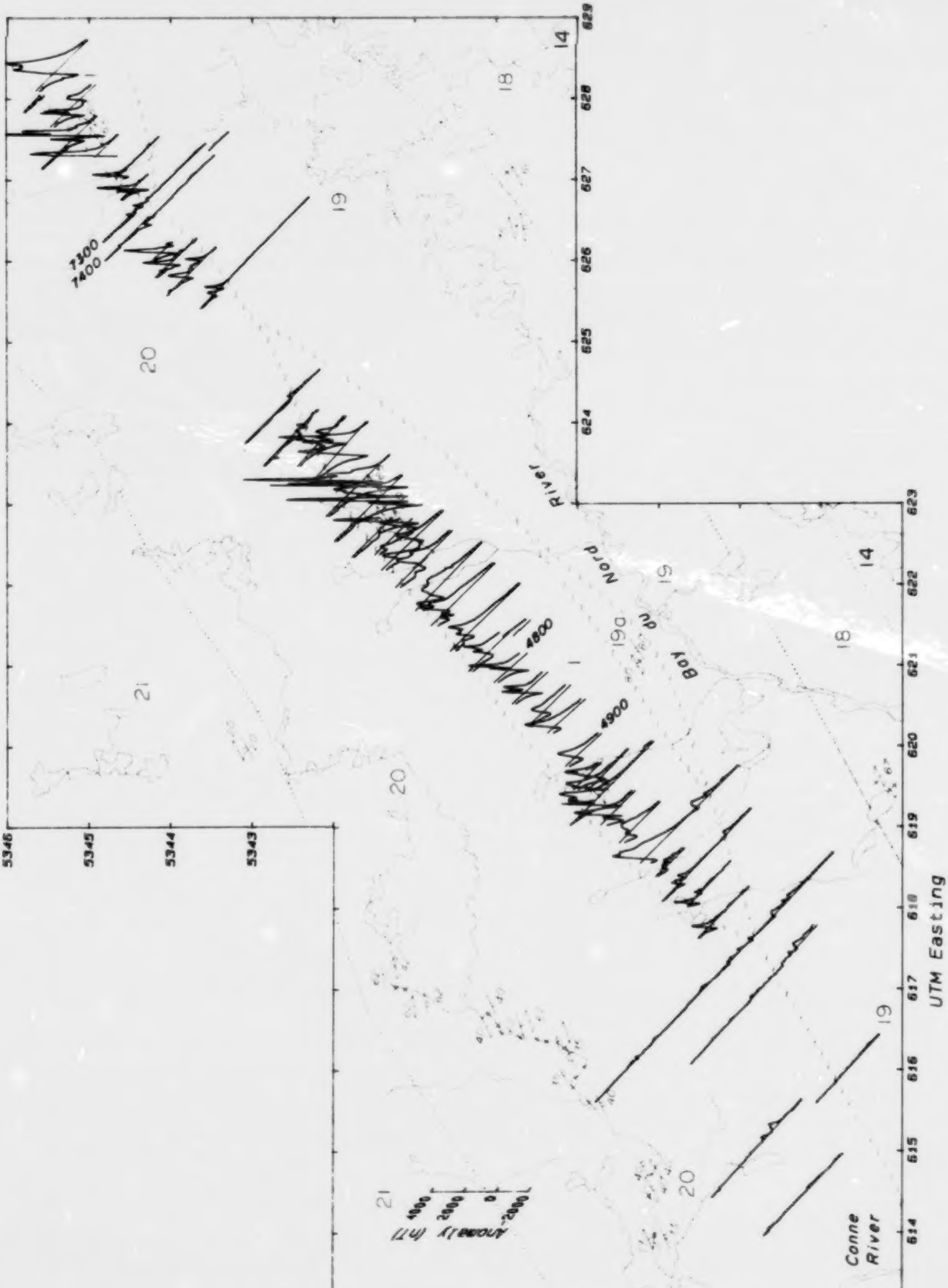

UTM Easting
UTM Northing
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
5335
5336
5337
5338
5339
5340
5341
5342
5343
5344
5345
5346
Anomaly (nT)
4000
2000
0
-2000
7300
7400
4800
4900
Conne River
Bay du Nord River
14
18
19
19a
20
21

Figure 6. *Total field magnetic data recorded along traverses in the Mount Sylvester (2D/6) map area. Largest and most variable anomalies recorded over outcrop of ultramafic rocks. Note strong asymmetry of anomalies. Geology and map unit numbers after Dickson (1986).*

LEGEND (Figure 6)

MIDDLE ORDOVICIAN AND YOUNGER?

Baie d'Espoir Group

North Steady Pond Formation

21 *Grey, medium-bedded, contact-metamorphosed(?), biotite–muscovite psammite and semipelite; locally highly altered with associated scheelite mineralization*

20 *Grey to buff, thin bedded sandstone with minor siltstone*

St. Joseph's Cove Formation

19 *Thin-bedded, pyritic, black slate and minor, thin, interbedded, coarse grained sandstone and siliceous, graphitic? siltstone;* 19a, *quartz-rich, medium-bedded sandstone*

18 Twillick Brook Member: *very thick bedded, strongly cleaved, coarse grained quartz–feldspar-crystal tuff and quartz-crystal tuff containing minor, interbedded coarse grained sandstone and siltstone, locally highly altered to gossan*

14 *Grey to buff, medium-bedded slate, siltstone and sandstone*

ORDOVICIAN OR OLDER

1 *Cleaved and sheared serpentinized peridotite and dunite; contains disseminated chromite and local talc layers*

SYMBOLS

Geological boundary (approximate, assumed)
Bedding, tops known (overturned)
Bedding, tops unknown (inclined)
Cleavage (first, second generation)
Fault (assumed)
× *Examined outcrop*

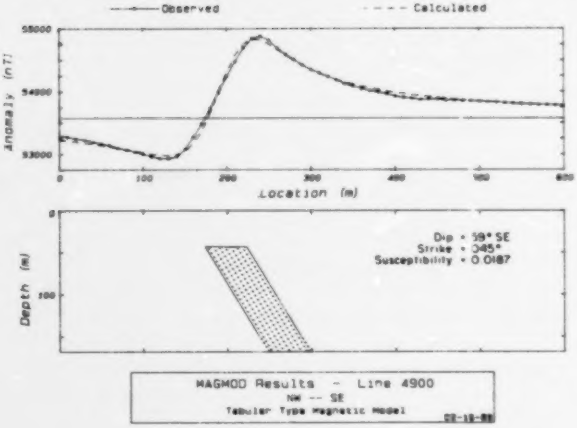


Figure 7. *Results of modelling the magnetic data for profile 4900 (see Figure 6 for location) with background field strength as indicated by solid line at 53,570 nT. A prism-shaped ultramafic body dipping 59° to the southeast and having magnetic susceptibility of 0.0187 cgs. evolves a fit to 0.071 standard deviation. The depth to the modelled body is 43 m and its true thickness is 26m. Magnetic inclination = 70.4°; magnetic declination = -24.5°.*

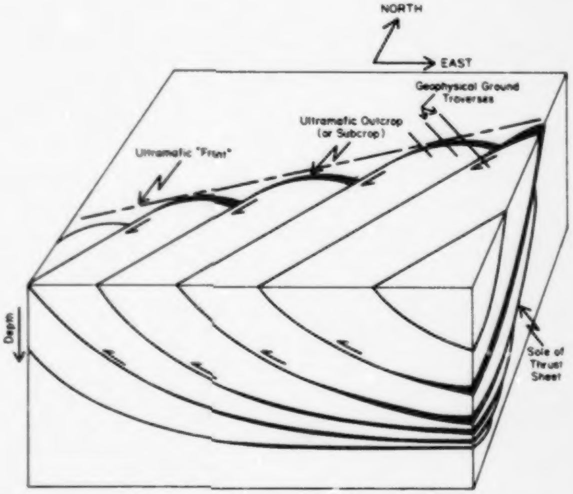


Figure 8. *Block diagram displaying imbricate thrust sheet model proposed to explain the apparent southeastward dip of ultramafic sheets (Figure 7), the observed step-like nature of the ultramafic front, and the sporadic occurrence of ultramafic outcrop with attendant magnetic anomaly. Ground geophysical traverses have relative orientations as illustrated.*

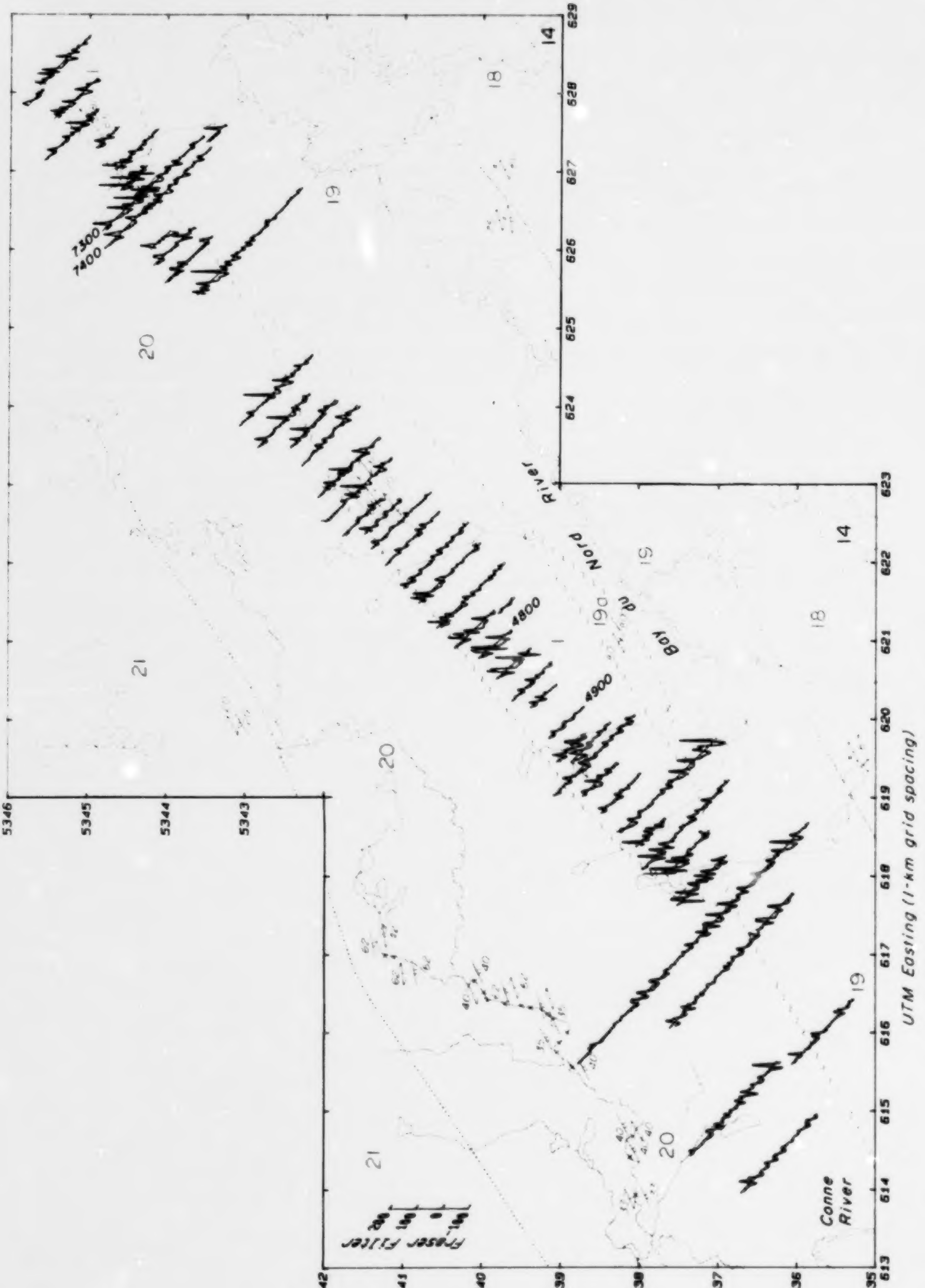

7300
7400
4800
4900
19
20
21
18
14
19a
20
21
19
18
14
19
20
Baie d'
Nord
River
Conne River
Fraser Filter
UTM Easting (1-km grid spacing)
UTM Northing (1-km grid spacing)
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
5335
5336
5337
5338
5339
5340
5341
5342
5343
5344
5345
5346

Figure 9. *Fraser filter values of VLF–EM inphase component recorded in the Mount Sylvester map area. Note good correlation of features on lines 7300 and 7400. Geology after Dickson (1986). (See Figure 6 for legend and symbols.)*

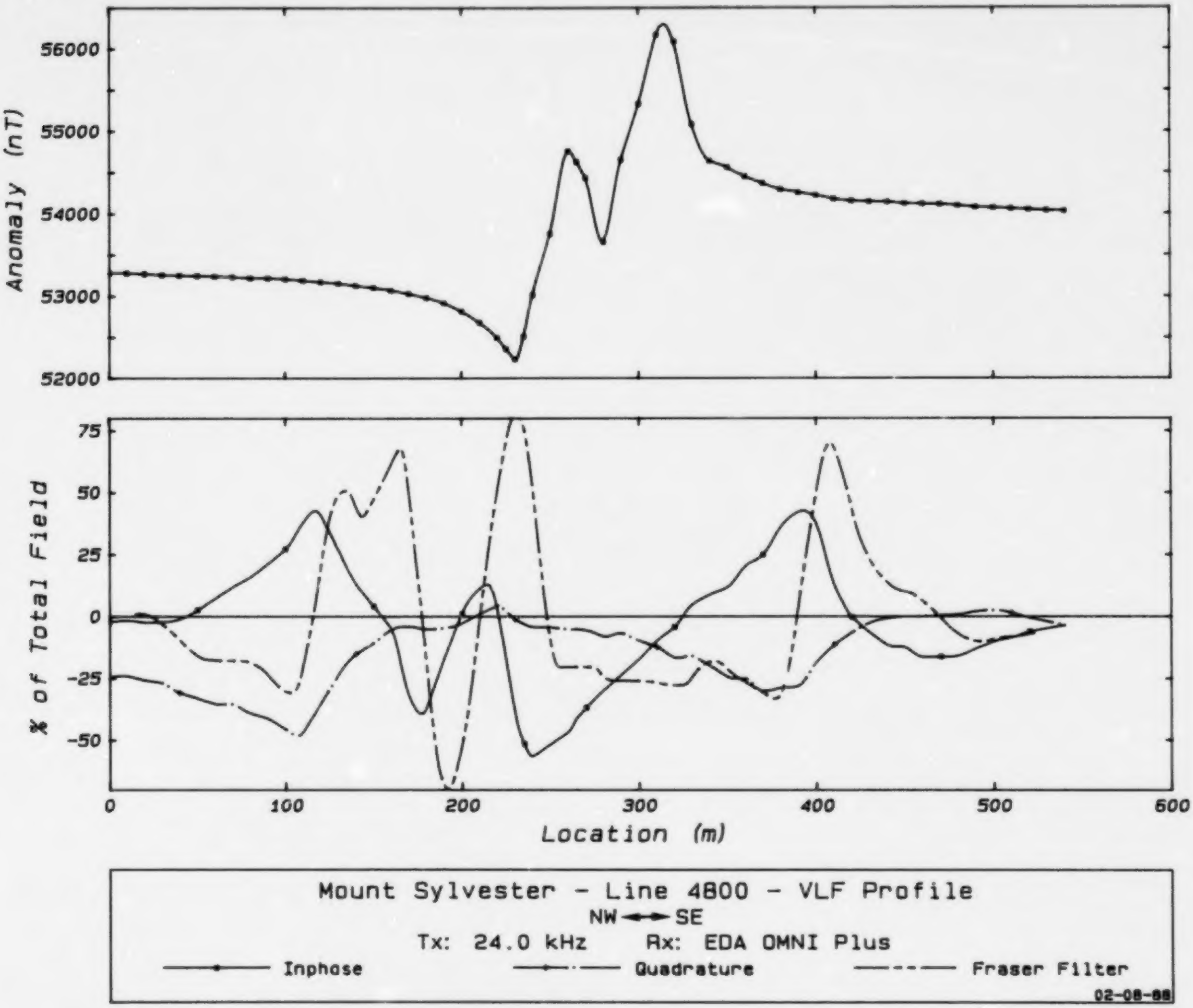


Figure 10. *Magnetic and VLF–EM profile data recorded along line 4800, Mount Sylvester area. See Figures 6 and 9 for location.*

EM field, many of the large-amplitude anomalies can be correlated on several profiles. Trends imposed by anomalies on adjacent traverses are oriented obliquely to the thrust front as are the individual magnetic fronts discussed above and displayed in Figure 6. A good example is illustrated on parallel Lines 7300 and 7400 of Figure 9, where similar topographic features were traversed. On lines of close proximity where peaks could be correlated, the trends coincide with those evident in the magnetic data.

On many profiles, one strong EM anomaly or a pair of anomalies exists to the northwest of the magnetic anomaly at the ultramafic front. The correspondence is readily observed in Figure 10, where a plot of recorded magnetic and VLF data collected along Line 4800 is shown. This northwestern Fraser filter anomaly is interpreted as reflecting the presence of a fault or sheared zone near the magnetic front, in which EM currents are preferentially channeled. Mapping of the EM anomaly associated with the magnetic front might enable mapping of the thrust fault across areas where the fault would be expected to exist but where the magnetic field is featureless.

In general, traverses showing anomalies having largest amplitude and highest frequency are located in areas of outcrop or thin drift (Figure 9). The VLF signature of bedrock becomes masked in regions of extensive conductive overburden. Therefore, in a qualitative sense, the EM field may also be used to estimate relative till thicknesses.

Conclusions

The sporadic occurrence of chromite-bearing ultramafic rocks in the Mount Sylvester map area is conceptually modelled as a series of truncated thrust fronts, several of which have been thrusted sufficiently to expose ultramafics

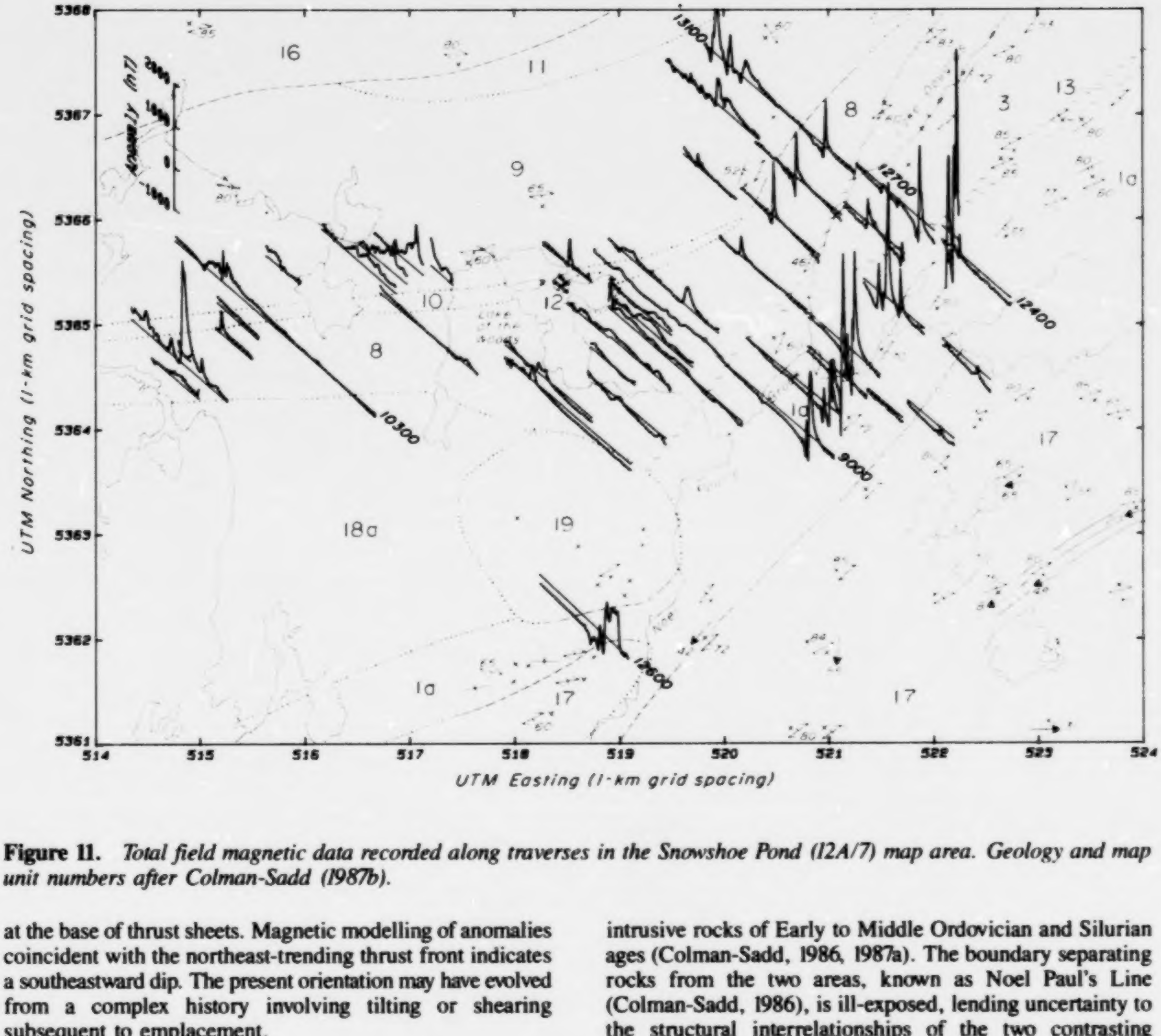


Figure 11. *Total field magnetic data recorded along traverses in the Snowshoe Pond (12A/7) map area. Geology and map unit numbers after Colman-Sadd (1987b).*

at the base of thrust sheets. Magnetic modelling of anomalies coincident with the northeast-trending thrust front indicates a southeastward dip. The present orientation may have evolved from a complex history involving tilting or shearing subsequent to emplacement.

SNOWSHOE POND

Objectives

The geophysical objectives in the Snowshoe Pond (12A/7) map area were to determine the signature of lithologic–structural features, particularly the two major shear zones that merge south of Lake Douglas (Colman-Sadd, 1987a,b, *this volume*), and to map these features through regions of extensive drift and vegetation cover where the general strike changes from a southwestward to a westward trend.

Geology and Previous Work

The geology of the southern part of the study area consists of Middle Ordovician polydeformed clastic metasedimentary rocks (Figure 11), intruded by several granitoid phases (Colman-Sadd, 1987a,b). Rocks to the northwest comprise sedimentary, volcanic and hyperabyssal intrusive rocks of Early to Middle Ordovician and Silurian ages (Colman-Sadd, 1986, 1987a). The boundary separating rocks from the two areas, known as Noel Paul's Line (Colman-Sadd, 1986), is ill-exposed, lending uncertainty to the structural interrelationships of the two contrasting geological terranes. Noel Paul's Line is interpreted locally as a ductile shear zone (Colman-Sadd, *this volume).*

Aeromagnetic data coverage consists of a regional survey by the Geological Survey of Canada (1968c,d) complimented by a combined, high-resolution, aeromagnetic and vertical magnetic gradient survey over the west half of the Snowshoe Pond map area and the entire Lake Ambrose (12A/10) map area to the north (Geological Survey of Canada, 1985a,b,e,f). A helicopter-borne, combined magnetic and EM survey (Aerodat Limited, 1983; Fitzpatrick, 1984) covers a gap in the recent high-resolution data for the area around Lake Douglas and overlaps with the recent high-resolution aeromagnetic data of the Geological Survey of Canada (1985a,e) to the north and west.

Access and Topography

Locations of the traverses surveyed in this study are displayed in Figure 11. Access into the surveyed area is

LEGEND (Figure 11)

SILURO-DEVONIAN

19 *Grey and pink, equigranular, medium grained, unfoliated biotite granite*

18a *Grey, moderately foliated, medium grained, porphyritic biotite granite; associated with garnet–muscovite aplite veins at its margins*

17 *Equigranular or locally megacrystic, strongly foliated, medium grained, grey or pink, biotite granite; locally mylonitic*

SILURIAN?

16 ROGERSON LAKE CONGLOMERATE: *Purple, clast-supported, polymictic conglomerate and sandstone*

ORDOVICIAN

13 *Mafic dykes; minor felsic intrusive rocks, and mafic volcanic rocks*

12 *Fine grained, dark-green gabbro*

11 *Lithic and quartz-crystal felsic tuff*

10 *Dark grey and black graphitic pelite with minor green volcanogenic sandstone beds*

9 *Volcanogenic, sedimentary rocks, rich in mafic volcanic clasts; includes laminated and thin-bedded sandstone and shale, thick-bedded sandstone and grit and unbedded conglomerate*

8 Mafic volcanic rocks; includes pillow lava, massive flows and volcanic breccia

3 *Thin-bedded and laminated phyllitic shale, siltstone and sandstone; includes unseparated limestone, graphitic shale and felsic tuff beds*

1 *Interbedded quartzite, psammite, semipelite and pelite, intruded by unseparated mafic dykes;* 1a, *includes black pyritic schist metamorphosed to greenschist and lower amphibolite facies*

SYMBOLS

Geological boundary (approximate, assumed)

Bedding, tops unknown (inclined, vertical)

Cleavage (inclined, vertical)

Lineation (age unspecified)

× *Exposure*

Fault (assumed)

Structural trend (from aerial photographs)

provided by a logging and powerline-access road to Lake Douglas. The topography of the area consists of densely forested ridges separated by extensive bogs in lowlands.

Interpretation of Magnetic Data

The structural trends of lithologies in the study area are readily apparent from the orientations of associated magnetic anomalies on recent aeromagnetic and vertical magnetic gradient maps for the west half of the Snowshoe Pond map area (Geological Survey of Canada, 1985a,b,c,d), but much less so on older aeromagnetic maps (Geological Survey of Canada, 1968c,d). On these maps, a high magnetic ridge associated with the volcanogenic sedimentary rocks (Unit 9) and the Rogerson Lake Conglomerate (Unit 16), in the west half of the area, appears to terminate abruptly just west of Lake Douglas, and is detected again 12 km to the north in the Lake Ambrose (12A/10) map area (Geological Survey of Canada, 1968d, 1985e,f). The Aerodat (1983) survey shows many of the more detailed geophysical features observed on the ground.

The most prominent magnetic anomaly observed on the ground, illustrated along Line 9000, at about 1600 m (Figure 12), is associated with a structure that trends to the northeast. This anomalous zone was detected on several traverses (Figure 11), including Line 12700 at position 800 m (see Figure 13). The large magnitude of the anomaly and its high frequency

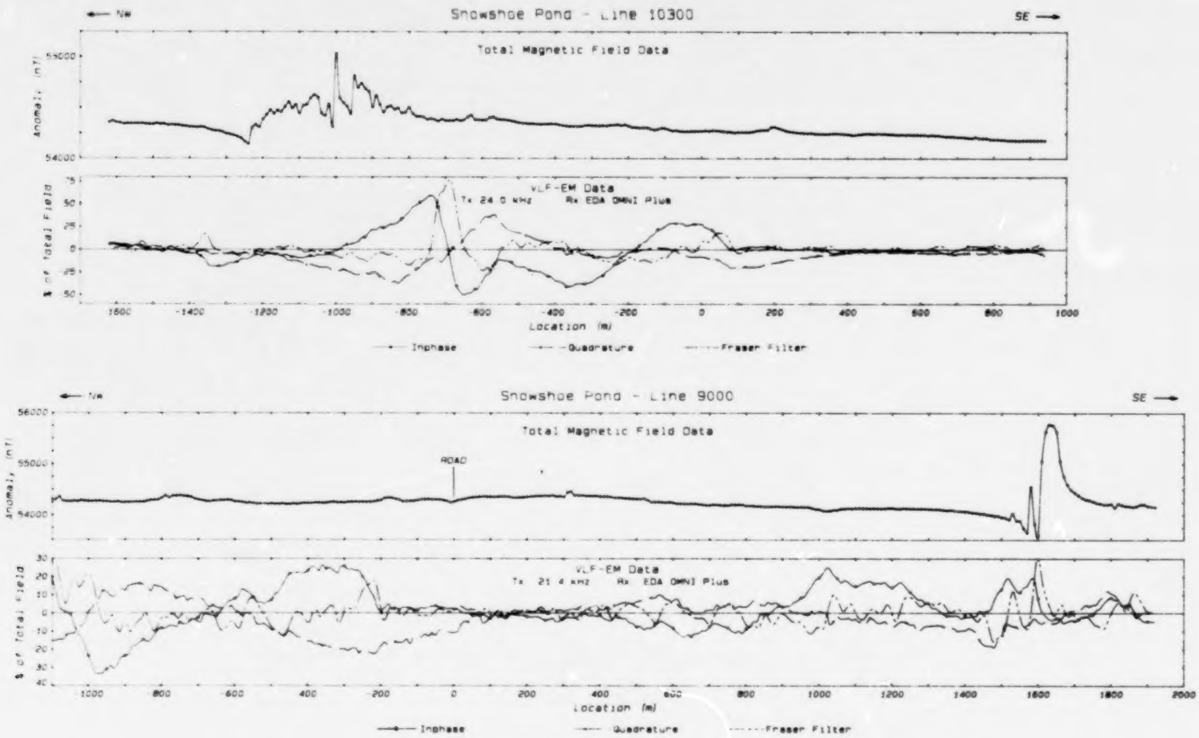


Figure 12. *Magnetic- and VLF–EM-profile data recorded along lines 9000 and 10300, Snowshoe Pond area. See Figures 11 and 14 for locations.*

content suggest the presence of a thrust fault within subunit 1a, bringing a magnetite-rich rock to very near the surface. Although outcrop along this magnetic feature is abundant, no rock types were observed other than highly deformed clastics of subunit 1a. The magnetic susceptibilities of these rocks have not been measured. Magnetic data from a helicopter-borne combined EM and magnetic survey of the Noel Paul's Brook (west) area (Aerodat Limited, 1983) indicate that this strongly magnetic zone trends southwestward to a west-trending, arcuate band of individual anomalies evident on recent high-resolution aeromagnetic maps (Geological Survey of Canada, 1985a,b), as parallel to, and south of Units 8 and 10 (Figure 11). This magnetic-anomaly linear emerges along trend on the southeastern corner of the Noel Paul's Brook map area (Geological Survey of Canada, 1985e,f), and coincides with the mapped position of highly deformed rocks of subunits 1a and 1b of Colman-Sadd (1987b).

Another prominent magnetic feature lies within Unit 8, which runs parallel to and northwest of Noel Paul's Brook (Figure 11). Individual anomalies form a lineament trending to the northeast, parallel to strike. The high-frequency peaks to the northeast suggest a near-surface, narrow magnetic layer. Anomalies defining this lineament broaden and decrease in magnitude to the southwest, such that the feature is barely discernible on Line 9000 (Figure 12). Such characteristics indicate a southward increase in source depth with final termination about 50 m northeast of Line 9000. The anomaly here may be caused by a thin lens of magnetic, cherty iron-formation, representing a depositional break within the massive mafic volcanic rocks of Unit 8. Alternatively, the feature may be caused by a mafic body, emplaced by shear or thrust faulting, as in the Mount Sylvester map area.

The small gabbro outcrops of Unit 12 (Figure 11) are uncharacteristically nonmagnetic. Two short surveys traversing exposed gabbroic rock show little magnetic contrast between the gabbros and their host rocks. Both are relatively nonmagnetic compared with the sedimentary rocks of subunit 1a. The Hungry Hill gabbro, in the Lake Ambrose map area (Kean and Jayasinghe, 1980), is similarly nonmagnetic (Geological Survey of Canada, 1985e,f), particularly in comparison with the strongly magnetic Harpoon Hill gabbro to the south (Kean, personal communication, 1988).

An anomalous magnetic zone was detected within the volcaniclastic sediments of Unit 9 northwest of its contact with Units 8 and 10 (Figure 11). The broad zone consists of several variable anomalies that may be observed on Line 10300 (Figure 12) between -1200 and -800 m and on Line 13100 (Figure 13) between -800 and -350 m. The variablity is thought to be related to alternating, fine grained sedimentary rocks and coarser grained layers rich in mafic volcanic clasts near the southeast contact of this volcanogenic sedimentary unit (Colman-Sadd, 1987b).

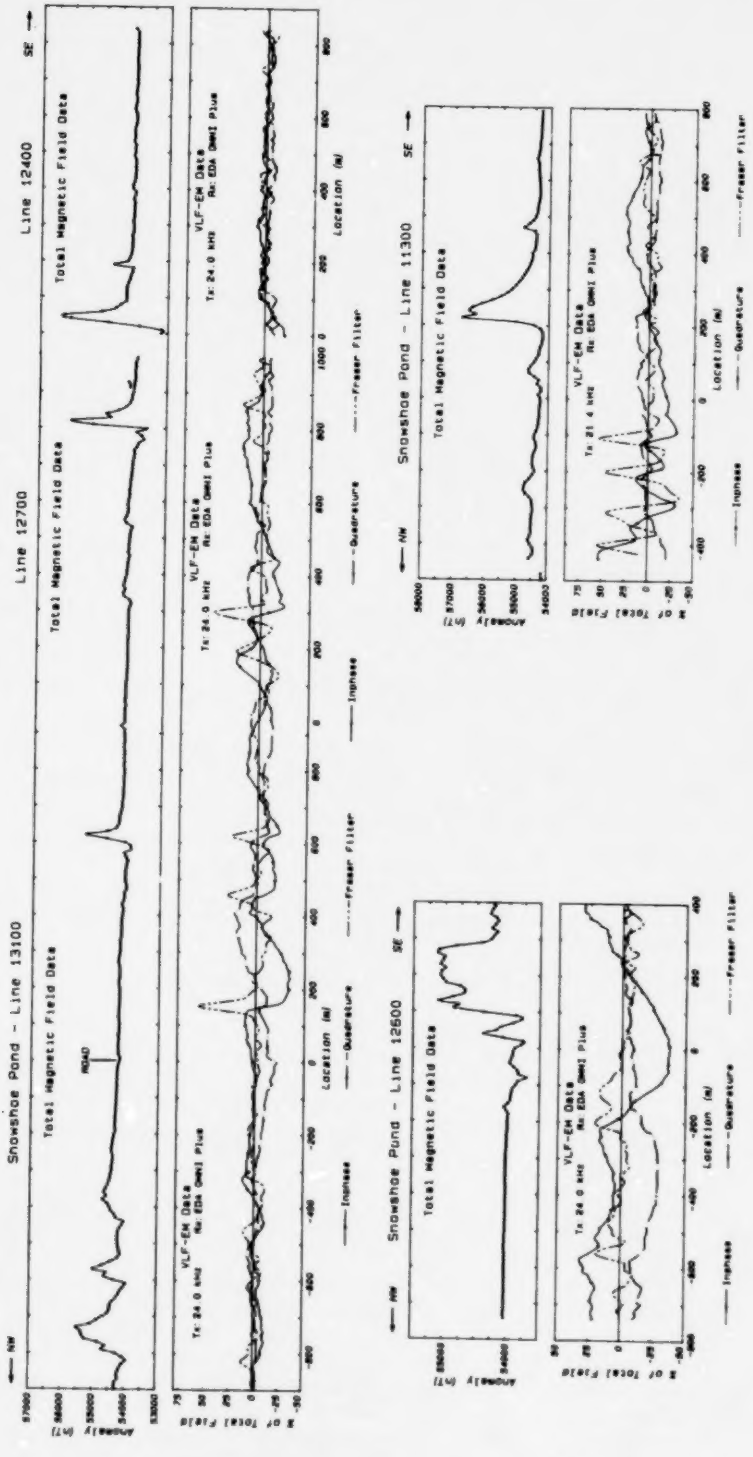


Figure 13. *Magnetic- and VLF–EM-profile data recording along lines 13100, 12700, 12400, 12600 and 11300, Snowshoe Pond area. See Figures 11 and 14 for locations.*

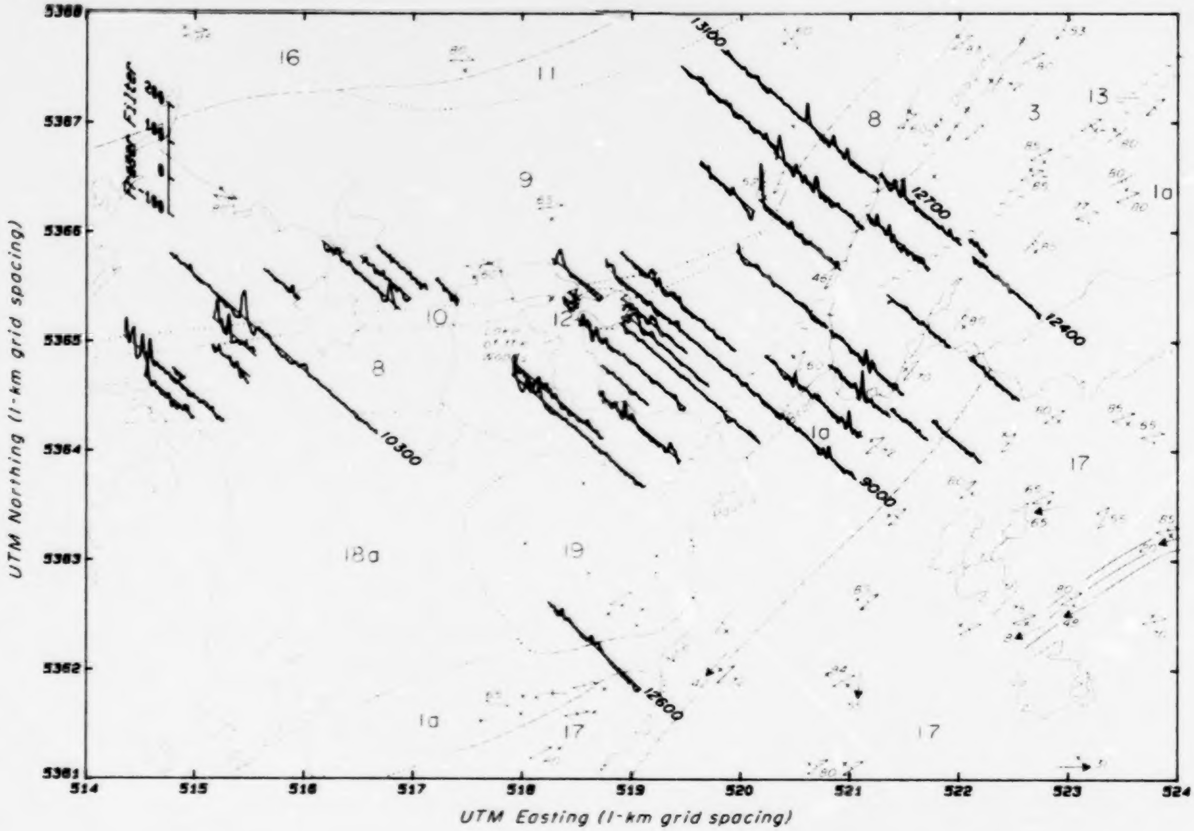


Figure 14. *Location plot of inphase Fraser filter anomalies for profiles in the Snowshoe Pond map area. Geology after Colman-Sadd (1987b). (See Figure 11 for legend and symbols.)*

Interpretation of VLF–EM Data

A major objective of the survey was to attempt to map out the positions of two major shear zones, identified geologically as coalescing in Noel Paul's Brook (Colman-Sadd, 1987a,b), using VLF–EM conductivity and to relate them to the structural geology and spatial distribution of lithologies. Unfortunately, peaks in the plot of Fraser filtered VLF inphase response (Figure 14) could not be correlated with either shear zone. Therefore, the shear is probably distributed through a wide zone, as in the Carmanville map area, and may presently be dry or lacking sufficient conductive mineral concentrations to give an anomalous halo zone.

The largest conductor observed in the surveyed area occurs at about position -700 m on Line 10300, (Figure 12), and coincides with the boundary between Units 8 and 9. This conductor has an associated large quadrature anomaly, indicating the presence of a good conductor. Figure 15 shows a pseudosection result of Karous-Hjelt filtering applied to the inphase anomaly (Karous and Hjelt, 1983). If the conductivity here arises from a fault contact, the symmetrical pseudosection contours suggest a near vertical orientation for the fault. This conductor correlates with that observed at the northwest extremity of Line 9000 (Figure 12). The conductive boundary between Units 8 and 9 can be traced for about 2 km east of Lake of the Woods (Figure 14), at which point it abruptly changes to a north-northeastward trend, and can be observed again near the 150-m mark of Line 13100 (Figure 13). On the basis of the VLF–EM signatures the boundary would be positioned about 70 m to the northwest of its mapped location. This is partly a consequence of the oblique survey orientation relative to the trend of the conductive horizon.

The four conductors on the northwest end of Line 11300 (Figure 13) coincide with the graphitic black shales of Unit 10.

The contact between undeformed granite (Unit 19), and sedimentary rocks of subunit 1a is very evident for both the magnetic and conductivity profiles (Line 12600, Figure 13). The contact is distinguished largely on its variable magnetic signature within the sediments, rather than any difference in magnetic values. On the basis of geophysical signatures, the contact between the units should be located 50 m to the northwest of its currently mapped position. The lack of outcrop near the traverse allows a sufficient degree of

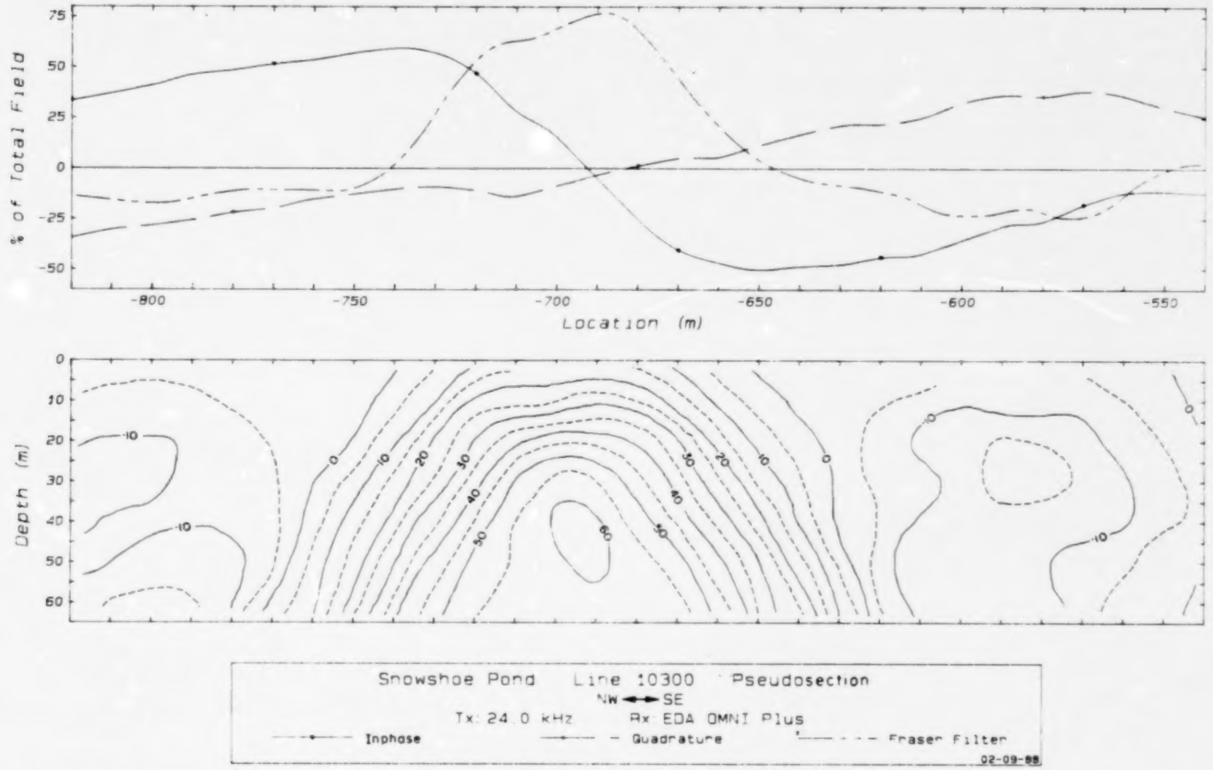


Figure 15. *Karous-Hjelt filtered pseudosection of conductivity underlying the large Fraser filter anomaly on line 10300 (see Figure 12). Symmetry of pseudosection contours indicates vertical orientation of conductor.*

freedom so that the contact position can be mapped geophysically. The southeastern end of this traverse also crosses into deformed granite (Unit 17) near the 270-m station as interpreted on the basis of an abrupt decrease in magnetic field strength. The associated magnetic anomaly appears to correlate, in relative magnitude and trend (Figure 11), with the anomalous magnetic zone detected on Line 9000.

Work has yet to be completed on orientations of contacts. However, in contrast to the asymmetric magnetic anomaly shape observed in the Mount Sylvester area, the symmetry of individual anomalies suggests a near vertical orientation of causative structures. Magnetic anomalies west of Lake of the Woods exhibit greater symmetry than those to the east, indicating that the structures to the east have a southeastward dip component.

Conclusions

1) Magnetic results of a survey conducted in the Lake Douglas area have defined several interesting anomalous zones within mapped lithologies that are otherwise undetected in surface outcrop. One zone, entirely within subunit 1a, is interpreted to be related to local thrust faulting. Thus, the extensive area mapped as deformed clastics of magnetic subunit 1a may represent structural repetition(s) of the unit. Subunit 1a may be repeated elsewhere by similar faults.

2) The mapped northeast-trending shear zones that converge at Noel Paul's Brook show little geophysical expression, particularly in the VLF–EM field, despite strong surficial evidence for their existence. The most plausible explanation is that the shear zones are dry and that units to either side have similar magnetic and conductive properties.

3) The abrupt change in lithologic trends from nearly east to north-northeast, which exists at Lake of the Woods is readily identified by shifts in trends of magnetic and VLF data. Units are probably cut off to the west by a northerly oriented fault.

4) Trends in the VLF Fraser filter plot follow those of the magnetic field, but generally are not as coherent in defining lithologies. Locations of zones defined by magnetic anomalies do not coincide with conductive horizons.

ACKNOWLEDGMENTS

The author wishes to acknowledge the very capable field assistance provided by Terry Denny despite being laden with cumbersome equipment in often difficult terrain. S.P. Colman-Sadd, P.P. O'Neill, W.L. Dickson and P. Davenport are thanked for their critical reviews of this manuscript.

REFERENCES

Aerodat Limited
1983: Report on a combined helicopter-borne magnetic and electromagnetic survey, Noel Paul's Brook (west) area, Newfoundland. Unpublished report, 42 pages. [12A/(374)]

Blackwood, R.F.
1980: Geology of the Gander (west) area (2D/15), Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-1, pages 53-61.

1982: Geology of the Gander Lake (2D/15) and Gander River (2E/2) area. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 82-4, 56 pages.

1983: Great Gull Lake (2D/6), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 82-71.

Colman-Sadd, S.P.
1986: Geology of the east part of the Snowshoe Pond (12A/7) area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 86-1, pages 179-188.

1987a: Geology of part of the Snowshoe Pond (12A/7) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 297-310.

1987b: Snowshoe Pond (12A/7), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File map 87-87.

This volume: Geology of the Snowshoe Pond (12A/7) map area.

Colman-Sadd, S.P. and Swinden, H.S.
1984: A tectonic window in Central Newfoundland? Geological evidence that the Appalachian Dunnage Zone may be allochthonous. Canadian Journal of Earth Sciences, Volume 21, pages 1349-1367.

Currie, K.L. and Pajari, G.E.
1977: Igneous and metamorphic rocks between Rocky Bay and Ragged Harbour, northeastern Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 77-1A, pages 341-345.

Currie, K.L., Pajari, G.E. and Pickerell, R.K.
1980a: Comments on the boundaries of the Davidsville Group, northeastern Newfoundland. *In* Current Research, Part A. Geological Survey of Canada, Paper 80-1A, pages 115-118.

1980b: Geological map of the Carmanville map area (2E/8), Newfoundland. Open File 721, Geological Survey of Canada, Ottawa.

Dickson, W.L.
1986: Mount Sylvester (2D/3), Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File map 86-66.

1987: Geology of the Mount Sylvester (2D/3) map area, Central Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 283-296.

Fitzpatrick, D.
1984: First year assessment report on Licence 2393, Lake Douglas, NTS 12A/7,10, for Noranda Exploration Company Limited. Unpublished report, 10 pages. [12A (370)]

Fraser, D.C.
1969: Contouring of VLF-EM data. Geophysics, Volume 34, 958-967.

1981: A review of some useful algorithms in geophysics. CIM Bulletin, Volume 74, 76-83.

Geological Survey of Canada
1968a: Mount Sylvester, Newfoundland. Aeromagnetic Series, Map 202 G (revised), scale 1:63,360.

1968b: Great Gull Lake, Newfoundland. Aeromagnetic Series, Map 191 G (revised), scale 1:63,360.

1968c: Snowshoe Pond, Newfoundland. Aeromagnetic Series, Map 193 G (revised), scale 1:63,360.

1968d: Noel Paul's Brook, Newfoundland. Aeromagnetic Series, Map 188 G (revised), scale 1:63,360.

1969a: Aeromagnetic map, Weir's Pond, Newfoundland, scale 1:63,360. Geophysics Paper 4474.

1969b: Aeromagnetic map, Carmanville, Newfoundland, scale 1:63,360. Geophysics Paper 4463.

1970: Botwood, Newfoundland, Aeromagnetic Series, Map 7348G, scale 1:250,000.

1984a: Magnetic anomaly map, Corner Brook, Newfoundland, scale 1:1,000,000. International Map of the World, Map NM-21-22-M.

1984b: Magnetic anomaly map, St. John's, Newfoundland, scale 1:1,000,000. International Map of the World, Map NK/NL-21/22.

1985a: Aeromagnetic total field map, Snowshoe Pond, Newfoundland, scale 1:50,000. Geophysical Series, Map C21141 G.

1985b: Aeromagnetic vertical gradient map, Snowshoe Pond, Newfoundland, scale 1:50,000. Geophysical Series, Map C41141 G.

1985c: Aeromagnetic total field map, 12A/7c,d, Newfoundland, scale 1:25,000. Geophysical Series, Map C21136 G.

1985d: Aeromagnetic vertical gradient map, 12A/7c,d, Newfoundland, scale 1:25,000. Geophysical Series, Map C41136 G.

1985e: Aeromagnetic total field map, Lake Ambrose, Newfoundland, scale 1:50,000. Geophysical Series, Map C21138 G.

1985f: Aeromagnetic vertical gradient map, Lake Ambrose, Newfoundland, scale 1:50,000. Geophysical Series, Map C41138 G.

Karous, M. and Hjelt, S.E.
1983: Linear filtering of VLF dip-angle measurements, Geophysical Prospecting, Volume 31, 782-794.

Kean, B.F. and Jayasinghe, N.R.
1980: Geology of the Lake Ambrose (12A/10)—Noel Paul's Brook (12A/9) map areas, Central Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 80-2, 29 pages.

McPhar Geophysics Limited
1969: Report on the combined airborne magnetic and electromagnetic survey on the NALCO project, Kaegudeck Lake area, Newfoundland. Unpublished report for NALCO Limited, 13 pages. [2D/3 (82)]

O'Neill, P.
1986a: Geology of the northwest corner of the Weir's Pond area (2E/1). Newfoundland Department of Mines and Energy, Mineral Development Division, Open File map 86-62.

1986b: Geology of the west half of the Weir's Pond area (2E/1). Newfoundland Department of Mines and Energy, Mineral Development Division, Open File map 86-61.

1987: Geology of the west half of the Weir's Pond (2E/1) map area. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 271-281.

This volume: Geology of Weir's Pond (2E/1) map area.

Peddie, N.W.
1986: International Geomagnetic Reference Field Revision 1985 by IAGA Division I, Working Group 1. Geophysics, Volume 51, 1020-1023.

Piasecki, M.A.J.
This volume: A major ductile shear zone in the Bay d'Espoir area, Gander Terrane, southeastern Newfoundland.

Rockel, E.R.
1973: Report on airborne electromagnetic and magnetic surveys of the Gander area, Newfoundland. Unpublished report for International Mogul Mines Limited of Canada by Kenting Earth Sciences Limited, 12 pages. [2E (341)]

Tuach, J.
1987a: Mineralized environments, metallogenesis, and the Doucers Valley Fault Complex, Western White Bay: A philosophy for gold exploration in Newfoundland. *In* Current Research. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 87-1, pages 129-144.

1987b: List of gold occurrences and deposits in Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Open File 1510 and accompanying Map 87-04.

Tuach, J., Dean, P.L., Swinden, H.S., O'Driscoll, C., Kean, B.F. and Evans, D.T.W.
This volume: Gold mineralization in Newfoundland: A 1988 review.

Zurowski, N.
1974a: Report on the exploration activities in the Gander-Ragged Harbour ultramafic belt. International Mogul Mines Limited. Unpublished report, 32 pages. [2E (338)]

1974b: Summary report on ground geophysical surveys in the Gander-Ragged Harbour ultramafic belt. International Mogul Mines Limited. Unpublished report, 19 pages. [2E (340)]

Note: Mineral Development Division file numbers are included in square brackets.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 437-445

DRILL-CORE REDUCTION—A PILOT STUDY

A. Harris
Publications and Information Section

INTRODUCTION

The Department of Mines initiated a drill-core collection and storage program in 1979. The stated objective of this program is to provide well maintained and representative collections of drill core from as many drilling programs as possible for the future use of the mineral exploration industry and other sections of the geoscientific community. Three core storage libraries were established with a combined maximum capacity of 260,000 m of core samples. The Pasadena core library is filled and approximately 9,000 m of core are being stored outside the building. The St. John's core library will be filled to capacity within the next several years. The Goose Bay core library will not have a space problem in the immediate future. The continued high level of mineral exploration in insular Newfoundland means a large increase in the amount of drill-core samples that will become available in the next several years.

The department has taken a two-pronged approach to the space problem by 1) pursuing expansion to existing facilities and acquiring or renting new core-storage facilities, and 2) adopting a policy of selective core collection and reduction. The department is in the process of acquiring a core-storage facility in Buchans, complete with all the core from the Buchans mine area, and presently is renting a facility in Springdale, which is 90 percent full.

Drill-core collection and reduction guidelines have been drafted and applied to some of the department's core collection from the Deer Lake Basin this year. This application forms a pilot study to assess the practicality of the core-reduction process and to further develop the guidelines. Results of the pilot study are presented here; the guidelines are contained in Appendix I.

PILOT-STUDY AREA

Core collection from the Deer Lake Basin (12H/6) (Figure 1) totals 10,826 m of core from 146 different drillholes. Practically all of these holes were drilled through rocks of the Deer Lake Group by Westfield Minerals Limited and Northgate Exploration Company Limited, while engaged in exploration for sandstone-hosted uranium deposits.

The primary reasons for choosing the Deer Lake Basin as the pilot-study area are the large size of the core collection from a single group of similar rocks, and the high density of drillholes in a number of small areas. In addition, the local and regional geology are well documented by numerous geological studies and mineral exploration reports.

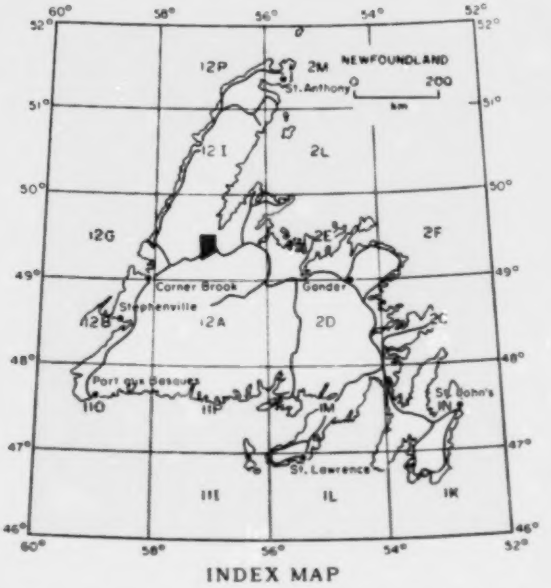
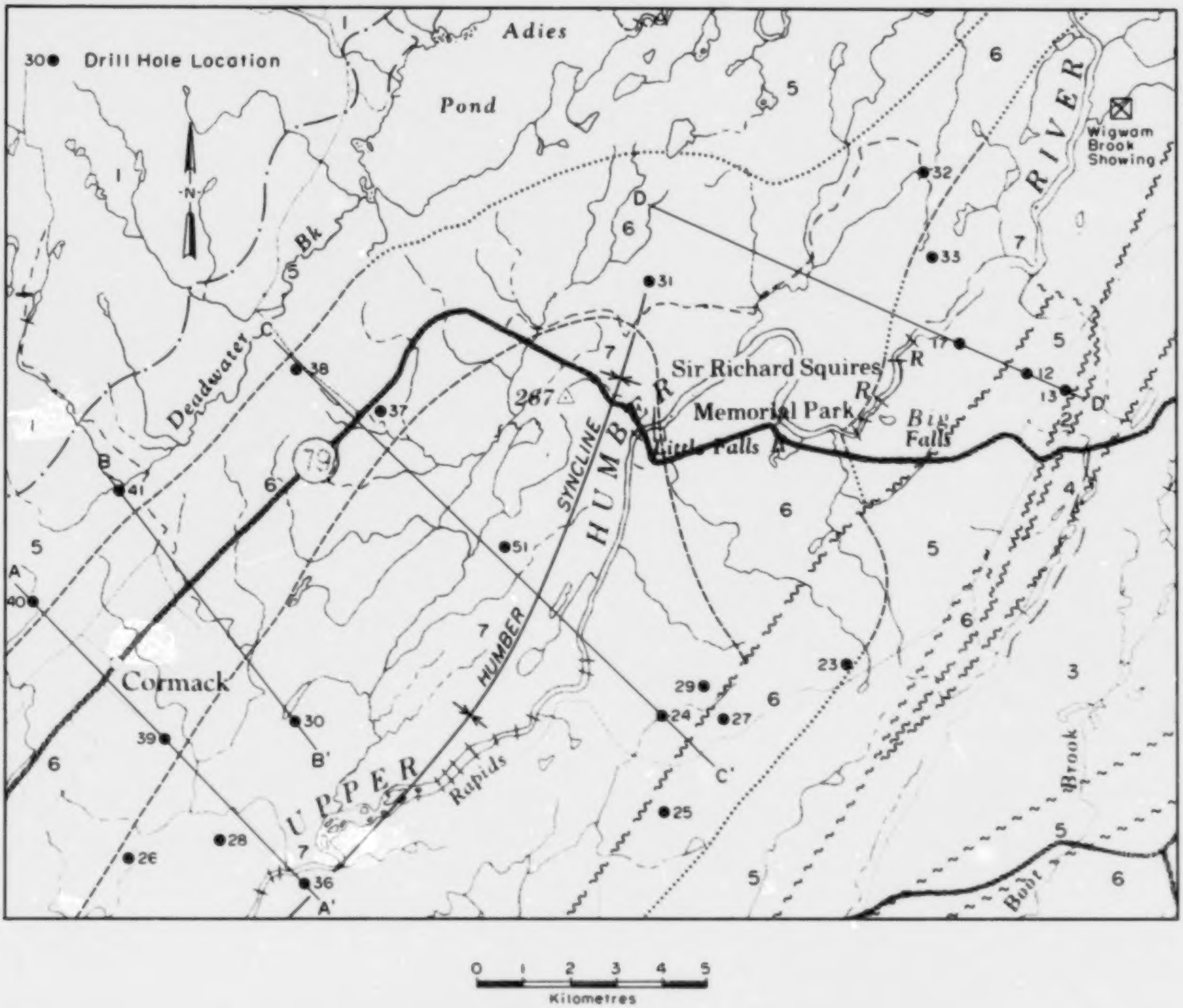


Figure 1. *Location of Upper Humber River area, Deer Lake Basin.*

General Geology (from Hyde, 1979, 1982)

The Carboniferous Deer Lake Group includes, in ascending order, the North Brook, Rocky Brook and Humber Falls formations in the Upper Humber River area (12H/6) (Figure 2). The Deer Lake Group is interpreted to unconformably overlie the early Carboniferous Anguille Group in this area.

The North Brook Formation consists of grey and red, pebble to boulder conglomerate, grey, orange and red sandstone, red siltstone, thin limestone beds and an amygdaloidal basalt flow. The North Brook Formation is interpreted as representing alluvial-fan deposition at basin margins, and braided- and meandering-river deposition on the alluvial-fan deposits. The North Brook Formation thickens southward where it has a maximum thickness of 1,300 m.


30● Drill Hole Location
N
Adies
Pond
Deadwater
Bk
Sir Richard Squires
Memorial Park
Little Falls
Big
Falls
HUMBER
R
SYNCLINE
UPPER
HUMBER
Rapids
RIVER
Wigwam
Brook
Showing
Cormack
79
287
Brook
Boot
A
A'
B
B'
C
C'
D
D'
0 1 2 3 4 5
Kilometres

LEGEND

CARBONIFEROUS

Visean

DEER LAKE GROUP (Units 5 to 7)

7 Humber Falls Formation: *grey, orange and red sandstone, pink to grey conglomerate, red and grey siltstone*

6 Rocky Brook Formation: *grey to green siltstone, mudstone, sandstone, limestone, brown oil shale*

5 North Brook Formation: *Red and grey pebble to boulder conglomerate, red to grey sandstone and siltstone, limestone*

Tournaisian

4 Wigwam Brook Formation: *red, brown and grey sandstone, conglomerate, limestone*

ANGUILLE GROUP

3 Saltwater Cove Formation: *dark-grey sandstone and siltstone, shale, mudstone, conglomerate, rare limestone and dolostone*

SILURIAN

SOPS ARM GROUP

2 *Felsic to intermediate volcanic rocks*

PRECAMBRIAN

1 *Granitic gneiss and undivided granitic plutons*

Figure 2. *Generalized geology of the Upper Humber River area, Deer Lake Basin (after Hyde, 1982; Map 82-7).*

The Rocky Brook Formation gradationally overlies the North Brook Formation and consists of the following rock types: red and grey siltstone and mudstone, dominantly fine grained red sandstone, grey calcilutite and calcarenite, and dark-brown oil shale. The Rocky Brook Formation was deposited in a fluvial environment at its base; shallow-lacustrine deposition dominates the rest of the formation. The Rocky Brook Formation thickens southward where it has a maximum thickness of 1,500 m.

The Humber Falls Formation, which consists of grey, pink and red arkose, arkosic pebble conglomerate and thin red siltstone beds, overlies the Rocky Brook Formation. The Humber Falls Formation has been assigned to the fluvial facies; deposition was by alluvial-fan sedimentation and by braided rivers. The maximum thickness of this formation is probably no more than several hundred metres.

Guidelines Application

Two different sets of drill-core samples from the Deer Lake Basin were chosen for this pilot study. One set is from closely spaced drillholes on the Wigwam Brook uranium prospect (Figure 3), and the other set is from widely spaced holes across the width of the basin in the Cormack area.

In order to assess the usefullness of drill-core samples from the Deer Lake Basin in understanding and recording the geology and mineral potential of the basin, the following studies were carried out:

1) a study of geological reports and company assessment reports;

2) a study of drillhole logs, drillhole sections and cross-sections through the basin, and individual mineral prospects; drafting of drillhole sections and cross-sections where necessary;

3) visual inspection of core samples to check condition of core and accurracy and consistency of drillhole logs.

The department's geofiles contain numerous geological papers and company assessment reports on the Deer Lake Basin (see Byrne, 1979a,b; Saucier, 1979; Patterson, 1981). These assessment reports by Westfield Minerals Limited contain lithological logs, drillhole sections, radiometric logs, assay results, geological cross-sections, reports on sedimentological studies, and other information that documents their exploration in the area. All of this material was used in assessing core from the basin. A section of drillhole WB-79-12 (Figure 4; Hiscott, 1979a) shows the type of detailed information available for reference in the core-reduction process.

After these steps were taken, the core-reduction guidelines were applied. Actual reduction of core samples will not take place until the department gives final approval to the core-reduction process.

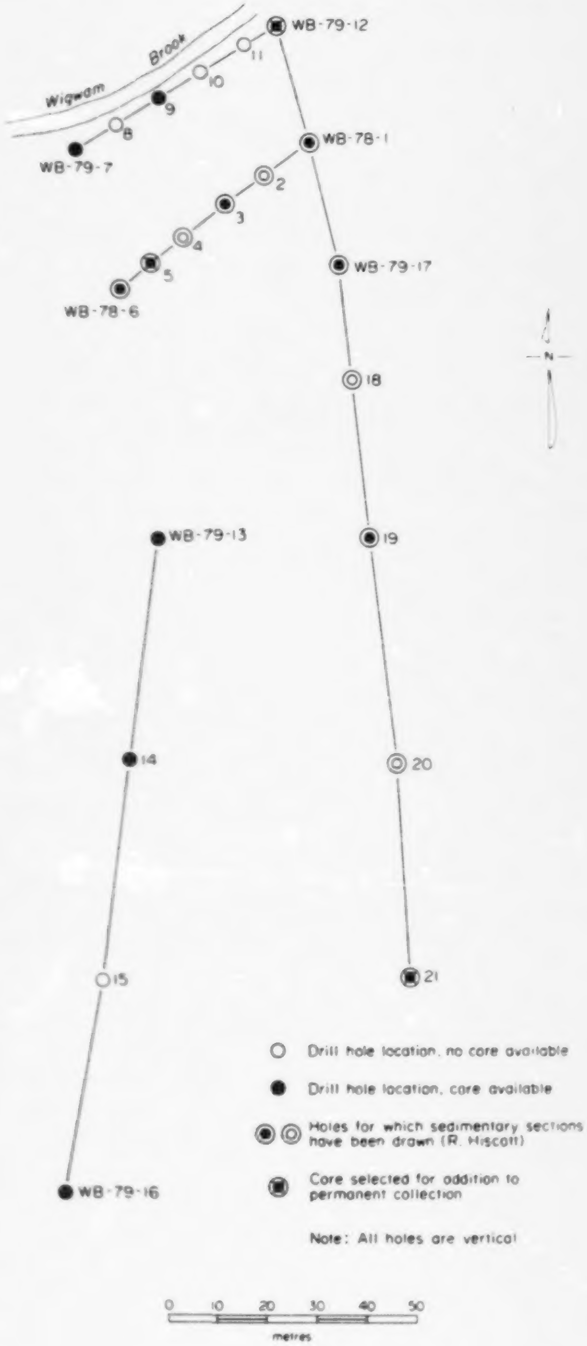

Wigwam Brook
WB-79-12
11
10
9
8
WB-79-7
WB-78-1
2
3
4
5
WB-78-6
WB-79-17
N
18
WB-79-13
19
14
20
15
21
WB-79-16
○ Drill hole location, no core available
● Drill hole location, core available
◉ ◎ Holes for which sedimentary sections have been drawn (R. Hiscott)
▣ Core selected for addition to permanent collection
Note: All holes are vertical
0 10 20 30 40 50
metres

Figure 3. *Wigwam Brook drillhole-location map.*

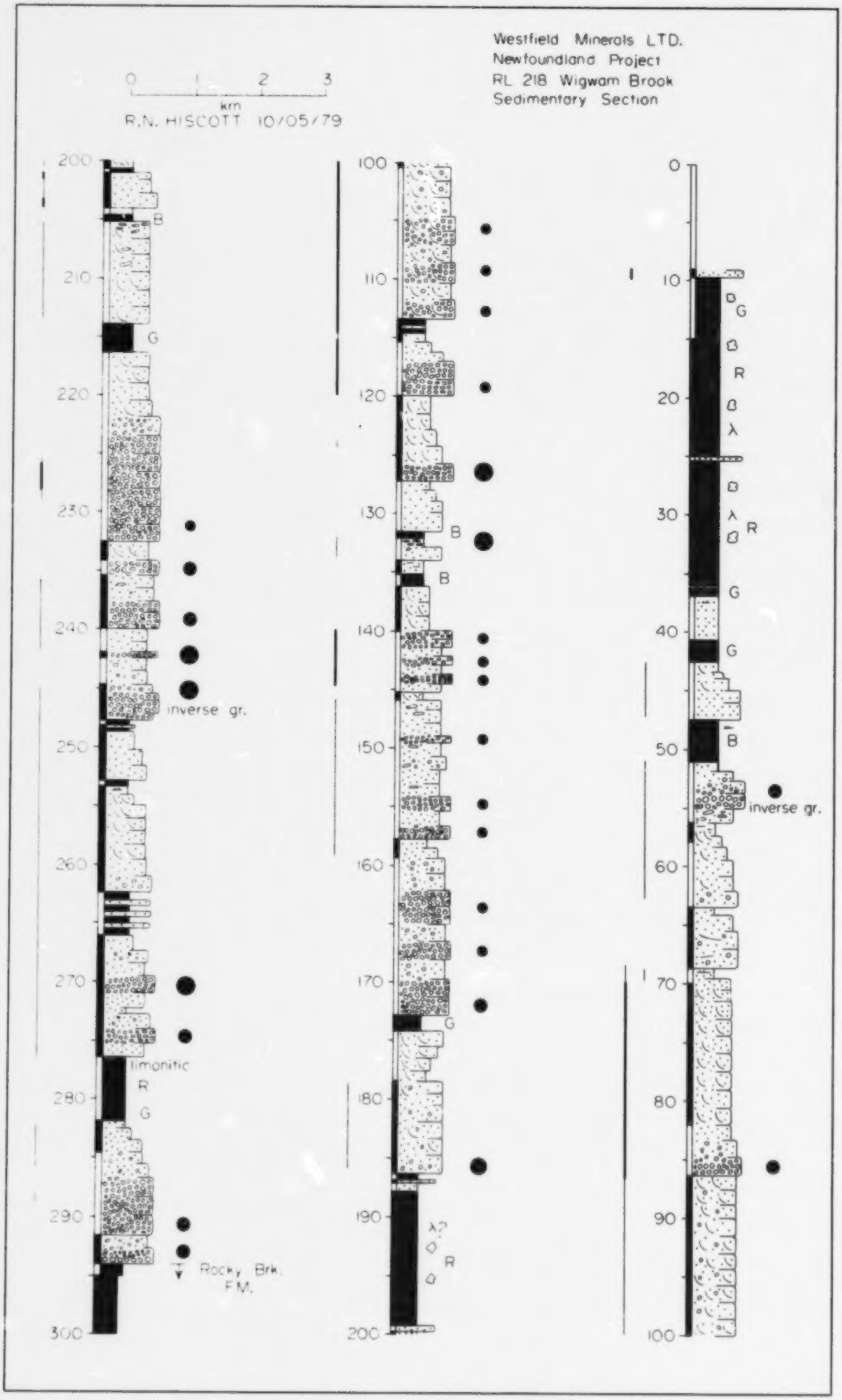
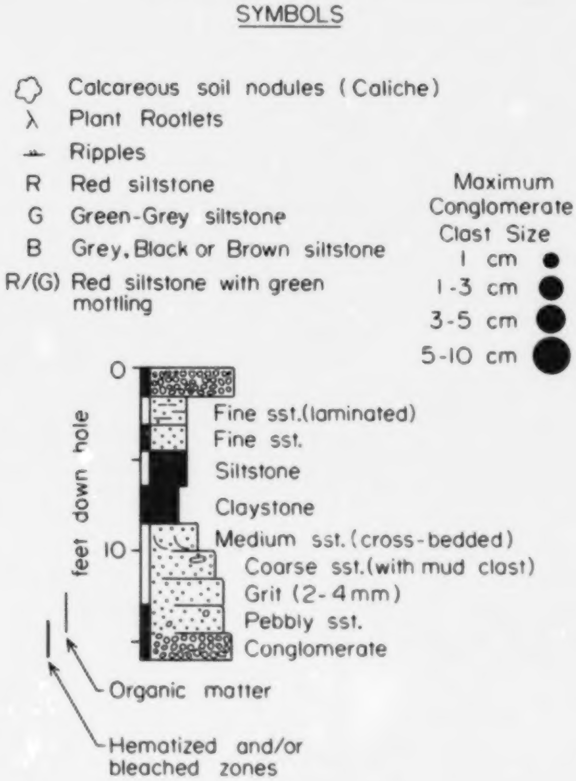

Westfield Minerals LTD.
Newfoundland Project
RL 218 Wigwam Brook
Sedimentary Section
0 1 2 3
km
R.N. HISCOTT 10/05/79
200
210
220
230
240
250
260
270
280
290
300
B
G
inverse gr.
limonitic
R
G
Rocky Brk. FM.
100
110
120
130
140
150
160
170
180
190
200
B
B
G
λ?
R
0
10
20
30
40
50
60
70
80
90
100
G
R
λ
λ
R
G
G
B
inverse gr.

Figure 4. *Cross-section through drillhole WB-79-12.*

SYMBOLS (Figure 4)


SYMBOLS
Calcareous soil nodules (Caliche)
λ Plant Rootlets
Ripples
R Red siltstone
G Green-Grey siltstone
B Grey, Black or Brown siltstone
R/(G) Red siltstone with green mottling
Maximum Conglomerate Clast Size
1 cm
1-3 cm
3-5 cm
5-10 cm
0
10
feet down hole
Fine sst.(laminated)
Fine sst.
Siltstone
Claystone
Medium sst.(cross-bedded)
Coarse sst.(with mud clast)
Grit (2-4mm)
Pebbly sst.
Conglomerate
Organic matter
Hematized and/or bleached zones

Wigwam Brook. The Wigwam Brook radioactive zone was discovered by Westfield Minerals in 1978 as a result of a ground radiometric survey. Subsequent trenching and diamond drilling of 21 shallow holes discovered highly radioactive sandstone boulders in overburden, and moderately radioactive zones at the 1.5-m to 4.5-m level in several drillholes, but no uranium mineralization was found in bedrock. A summary of diamond drilling at Wigwam Brook is given in Table 1.

The drillhole-location plan is shown in Figure 3. The department is presently storing core from thirteen of the twenty-one holes drilled.

All drillholes are collared in the Humber Falls Formation and only three penetrated the calcareous shales of the upper part of the Rocky Brook Formation. These three deeper holes permit a description of the entire Humber Falls sequence at Wigwam Brook. They are too widely spaced to permit detailed correlations between individual units. However, all three holes contain the same rock types in varying thicknesses, and although the exact stratigraphic position of rock units are not replicated, the gross stratigraphy is similar.

A sedimentological study of the Humber Falls Formation in the Wigwam Brook area (Hiscott, 1979a,b), utilizing the core samples, conclud d that 'lateral continuity in the Humber Falls Formation is poor, particularly in the coarse-grained intervals where channelling is believed to be common. Only thick siltstone units can be used as reliable horizons for correlation purposes.'

Table 1. *Wigwam Brook–drillhole summary*

Hole No.	Depth (m)	Dip	Collared In	Terminated In	Core Availability (% Stored)
WB-78-1	39.6	−90°	Humber Falls Formation	Humber Falls Formation	90
WB-78-2	39.6	−90°	Humber Falls Formation	Humber Falls Formation	0
WB-78-3	44.4	−90°	Humber Falls Formation	Humber Falls Formation	78
WB-78-4	45.7	−90°	Humber Falls Formation	Humber Falls Formation	0
WB-78-5	110.6	−90°	Humber Falls Formation	Rocky Brook Formation	65
WB-78-6	42.6	−90°	Humber Falls Formation	Humber Falls Formation	92
WB-79-7	36.5	−90°	Humber Falls Formation	Humber Falls Formation	92
WB-79-8	36.5	−90°	Humber Falls Formation	Humber Falls Formation	0
WB-79-9	35.7	−90°	Humber Falls Formation	Humber Falls Formation	74
WB-79-10	36.5	−90°	Humber Falls Formation	Humber Falls Formation	0
WB-79-11	36.5	−90°	Humber Falls Formation	Humber Falls Formation	0
WB-79-12	94.5	−90°	Humber Falls Formation	Rocky Brook Formation	85
WB-79-13	30.4	−90°	Humber Falls Formation	Humber Falls Formation	90
WB-79-14	30.4	−90°	Humber Falls Formation	Humber Falls Formation	74
WB-79-15	30.4	−90°	Humber Falls Formation	Humber Falls Formation	0
WB-79-16	30.4	−90°	Humber Falls Formation	Humber Falls Formation	90
WB-79-17	30.4	−90°	Humber Falls Formation	Humber Falls Formation	90
WB-79-18	30.4	−90°	Humber Falls Formation	Humber Falls Formation	0
WB-79-19	30.4	−90°	Humber Falls Formation	Humber Falls Formation	92
WB-79-20	30.4	−90°	Humber Falls Formation	Humber Falls Formation	0
WB-79-21	101.8	−90°	Humber Falls Formation	Rocky Brook Formation	100

Stratigraphically, the three deeper holes are representative of the Humber Falls Formation in the Wigwam Brook area. Therefore all the core samples from these three holes will form the permanent collection from this area.

As there are no mineralized zones in any of the remaining ten holes, these samples will be reduced and a minimum of 25 percent kept, i.e., one-half-metre core retained for every two-metre section. Where this is not sufficient to show all of the rock types, variations in rock types and different structural features, more core will be retained to show these features. As the object of the core-reduction process is to discard only the obviously 'redundant' core samples, when there is some doubt as to whether core should be kept or discarded, it will be kept. In addition, a photographic record will be made of all core before it is condensed.

Cormack Area. The department is presently storing 2,524 m of core samples from widely spaced drillholes (22) within the Deer Lake Basin between Adies Pond in the north and the town of Deer Lake in the south. Drillhole sections for all of these holes are available from company assessment reports, and stratigraphic cross-sections across the basin (AA, BB, CC and DD) have been completed (Figure 2).

These core samples define the boundaries of the basin in that area, and give complete sections through the Rocky Brook Formation and partial sections through the North Brook and Humber Falls formations. The wide spacing of these drillholes and the variability of depositional environments within the same formation make the correlation of individual rock units impossible. Therefore, the application of the core-reduction guidelines to this set of core samples dictates that all samples be kept from drillholes that define the borders of the basin, and that core samples from the deepest holes representative of the stratigraphy through the centre of the basin be also kept. The only samples to be considered for core reduction will be those from adjacent holes that exhibit similar stratigraphy. And, of course, all mineralized sections will be kept intact.

SUMMARY

Geological mapping and mineral exploration work provide a comprehensive written record of the geology of the Deer Lake Basin. The preservation of drill-core samples provides a useful data base for future geological investigations and mineral exploration. However, core-storage space and project funding permit the preservation of *representative* drill-core samples only. Therefore, drill-core collection and reduction guidelines must be applied. These guidelines are designed to ensure that sufficient representative core samples are retained for future use and that any core samples discarded are well described by written and photographic records. A review of all available data on the core samples described in this report, and the examination and partial relogging of some 3,180 m of core samples from 45 holes, indicate that core reduction can be carried out by following existing guidelines without seriously compromising the drillhole information available for the Deer Lake Basin.

It is apparent that little core reduction can be undertaken with samples from the widely spaced holes. However, samples from closely spaced drillholes, e.g., at Wigwam Brook, through the same stratigraphy can be reduced. Application of the core-reduction guidelines to the Wigwam Brook samples will result in a 40 percent reduction in the amount of core currently being stored from that particular project. The future application of the guidelines to selected core-sample suites in all of the department's core-storage facilities will result in more efficient use of existing core-storage capacity. This will aid the core-storage program in meeting its primary objective of preserving representative core samples from as many drilling projects as is possible.

REFERENCES

Byrne, C.
1979a: A report on uranium mineralization located at Wigwam Brook on Reid Lot 218, Deer Lake, Newfoundland. Westfield Minerals Limited. Unpublished report, 11 pages. [12H/6/549]

1979b: Results of uranium exploration on Reid Lots 35, 36, 38, 40, 142 and 218. Westfield Minerals Limited. Unpublished report, 100 pages. [Nfld./704]

Hiscott, R.N.
1979a: Sedimentology of the Humber Falls Formation, Wigwam Brook, Reid Lot 218, Drill Core Study. *In* unpublished report by J. Tuach, 1980. Westfield Minerals Limited, 20 pages. [12H/6/647]

1979b: Some impressions concerning regional trends in the Humber Falls Formation, Northern Lobe. *In* unpublished report by J. Tuach, 1980. Westfield Minerals Limited, 5 pages. [12H/6/647]

Hyde, R.S.
1979: Geology of Carboniferous Strata in portions of the Deer Lake Basin, Western Newfoundland. Newfoundland Department of Mines and Energy, Mineral Development Division, Report 79-6, 43 pages.

1982: Geology of the Carboniferous Deer Lake Basin. Newfoundland Department of Mines and Energy, Mineral Development Division, Map 82-7.

Patterson, M.
1981: Report on geological, geochemical and geophysical exploration in Reid Lot 218. Westfield Minerals Limited. Unpublished report, 42 pages. [12H/6/709]

Saucier, A.E.
1979: Evaluation of the Uranium Potential in the Deer Lake Basin of Newfoundland, Canada. *In* unpublished report by J. Tuach, 1980. Westfield Minerals Limited. [12H/6/647]

Note: Mineral Development Division file numbers are included in square brackets.

APPENDIX I

DRILL-CORE COLLECTION AND REDUCTION GUIDELINES

I CLASSIFICATION OF DRILL-CORE COLLECTIONS

The collection of mineral exploration core will fall into three categories, based on collection from a single mineral exploration prospect.

1) Permanent collection

The permanent collection will consist of:

i) type stratigraphic sections (complete drillholes);
ii) representative mineralized sections (complete drillholes) may be made available for sampling on a limited basis, but as a rule the permanent collection will not be available for sampling.

2) Working collection

The working collection will contain:

i) Intact mineralized sections
ii) Condensed sections of redundant country rock, and footwall–hanging-wall sections
iii) Sufficient number of complete holes will be kept to show contacts and alteration patterns where identifiable

3) Confidential core collection

i) accomodate all reasonable requests for space where space is available;
ii) when core becomes open, selection of permanent and working collections will be made

II CLASSIFICATION OF DRILL-CORE SOURCES

The sources of drill-core samples considered for storage in our core libraries can be classified as follows:

1. Small prospects (1 to 5 drillholes)
2. Developed prospects (more than 5 drillholes)
3. Active mine
4. Abandoned mine:
   i) insignificant or no known reserves
   ii) known reserves, possible future reactivation
5. Other:
   i) geotechnical drilling

The following guidelines will be applied when considering core samples for collection and addition to our core libraries:

1. Small prospects

i) Permanent collection:

The permanent collection will consist of 1 to 2 drillholes that best exhibit the mineralogy, structural features and stratigraphy of the prospect. The geological complexity of the prospect, degree of exposure, amount of data available, and how well the regional metallogenesis is understood will determine if more than two drillholes are to be included in the permanent collection. (The input of project geologists who have mapped particular areas will be invaluable in making decisions on the makeup of the permanent collection.)

ii) Working collection:

Mineralized portions will be stored intact; barren country rock will be condensed. Samples will be limited to those necessary to illustrate the various rock types and their megascopically identifiable petrographic and structural features.

2. Developed prospects

i) Permanent collection:

Sufficient drillholes will be collected and added to the permanent collection to show the character of the deposits, e.g., mineralogy, alteration, structural features and stratigraphy. Additional drillholes that show variations in these features will be collected and/or retained. Drillholes that establish the physical boundaries of the prospect will be added to the permanent collection, and those showing typical stratigraphy outside of mineralized zones will be kept.

ii) Working collection:

Depending on drilling density, 25 to 50 percent of remaining drillholes, after the permanent collection has been selected, will be condensed and stored. Mineralized sections will be stored intact. Any core samples remaining will be preserved (boxed, relabelled and stacked) on site.

Exceptions to this practice include developed prospects that appear headed toward production where attempts will be made to preserve all drill-core samples. All samples will continue to be stored on-site or in the Department's core libraries until the economic viability of the deposit has been established. Similar considerations apply to remote mineral prospects in Labrador.

3. Active Mine

i) Permanent collection:

Drillholes that are representative of the mineral deposit(s), the mine and local geology will be solicited from the mine operator. There will not be a working collection as department staff have access to core samples in company storage.

4. Abandoned mine

i) Permanent collection—no known reserves:

The permanent collection will consist of sufficient core samples (complete drillholes) to show local geology, mine geology, and significant variations and character of mineralization of the deposit(s), and any other geological features unique to the deposit and mine area. There will not be a working collection in our core libraries, but where possible all remaining core, after selection of permanent collection, will be preserved on site.

ii) Permanent collection—known reserves (possible future reactivation):

All core samples that could possibly be useful in expanding reserves of the mine (basically everything except closely spaced production drilling in mined-out areas) will be added to our permanent collection. Core from production drilling in mined-out zones will be discarded. Core samples will be preserved on the mine site (indoors) where possible. After a period of at least 10 years from mine closure, and with consideration of land disposition and exploration during the 10-year period, the status of our core collection will be reviewed. At this time it is likely that a smaller permanent collection and a working collection will be selected for continued storage in our core libraries.

iii) Working collection—known reserves (possible future reactivation):

A working collection will not be selected until 10 years after the mine is closed. All core will have permanent-collection status for 10 years, and sampling will be permitted only by a company making a serious and organized attempt to re-open the mine.

5. Other

Drill-core samples in this category include samples from geotechnical drilling projects, such as well drilling and hydroelectric projects. Lithological logs will be compiled for core samples in this category and a representative drillhole or drillholes will be added to the permanent collection, depending on drilling density in the area and what new data the core samples may add to our collection.

III EXCEPTIONS TO CORE-REDUCTION GUIDELINES

Any core samples available to us that fit into either of the categories below will be collected intact and will be placed primarily into the permanent collection:

1. Core samples from 'new' areas where very little previous mineral exploration or drilling has been done.
2. Core samples acquired as the result of drilling for 'new' commodities, e.g., platinum-group metals in the Bay of Islands area.
3. Core samples from areas of heavy drift cover, e.g., potash exploration, Bay St. George area.

IV PROCEDURES FOR CONDENSING DRILL CORE

1) Before core is condensed, drillhole logs, assays and cross-sections must be collected or compiled by the core-storage project geologist. If company logs and sections are not available or lack sufficient detail, the core should be relogged and new sections drawn.

2) If drill-core samples are from an area mapped by one of our project geologists, he/she will be consulted before the core is condensed.

3) Only core samples in the working collection will be condensed. The mineralized sections will be stored intact, and the country rock will be sampled at regular intervals, depending on stratigraphy, structural features and variations in rock types.

4) Sampling will be permitted from the working collection. Sampling will be permitted from the permanent collection with the proviso that a half split of core must remain for continued storage.

5) Core samples to be discarded will be systematically chip sampled to provide material for future assay and analysis.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 447-452

CORE-STORAGE PROGRAM, 1987

A. Harris and S. Cochrane
Publications and Information Section

INTRODUCTION

During 1979, the Newfoundland Department of Mines and Energy began a drill core collection and storage program. The objective of this program is to provide well-maintained and representative collections of drill core for the future use of the mineral exploration industry, government and university geoscientists and other geotechnical people.

DRILL CORE COLLECTION

During 1987, drill core collection continued in insular Newfoundland. A total of 60,872.8 m of drill core were added to our collection this year. Of this total, 48,880.5 m were acquired from Western Canadian Mining (old Brinex drilling) when the department leased a core-storage building located on the former Brinex base camp at Springdale. Another 5,608.5 m of core were collected by project personnel and 6,389.2 m of core were delivered to our facilities, for confidential storage, by mineral exploration companies.

Activities in Labrador this past year were limited to the inspection of company core-storage sites in the eastern part of the Central Mineral Belt and in western Labrador, and the cataloging of core collected during 1986.

Approximately 246,800 m of drill core are now being stored. Figures 1 and 2 show the locations of all sites where core has been collected and Tables 1 and 2 give a list of the collected core. Recently acquired confidential core, some condensed core and core acquired with the Springdale facility but not cataloged because of insufficient data are shown as 'Other' in Table 1.

DRILL-CORE LIBRARIES

The Department of Mines now operates four core-storage libraries located at St. John's, Pasadena, Goose Bay and Springdale (Figure 3). The St. John's library is staffed on a full-time basis except during the field season. It has a capacity of 60,000 m of drill core and now houses approximately 38,365 m of drill core samples. The St. John's library is equipped with a rock saw, a stereomicroscope, a magnetic-susceptibility meter, a resistivity meter, an ultraviolet light and a McPhar TV-1 scintillometer. This facility and equipment are available for use on approved projects by exploration geologists, university researchers, staff of the Department of Mines and other interested persons.

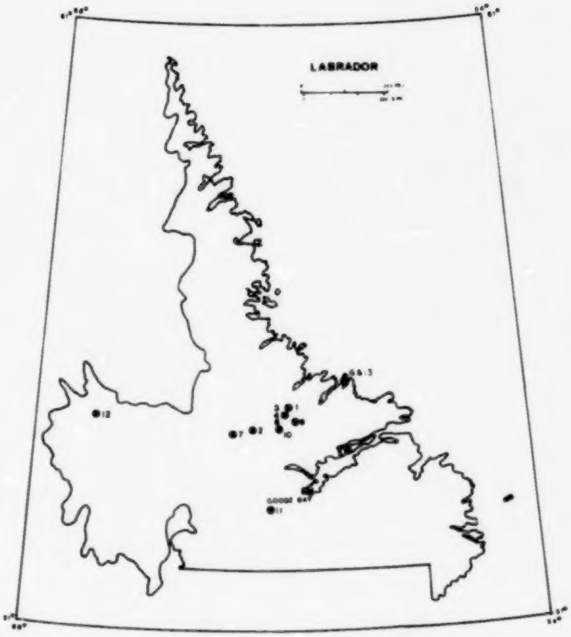


Figure 1. *Core-collection sites, Labrador.*

The Pasadena core library is also staffed on a full-time basis. This library has equipment similar to the St. John's library along with a ventilated room for storing radioactive core and a humidity-controlled room for storing salt core. The Pasadena core library is near full capacity with only a little working space remaining for new core additions.

The Goose Bay core library, which contains core from Labrador, is not staffed on a full-time basis. It has facilities similar to, and shares equipment with, the St. John's core library.

The Springdale core library is not staffed on a full-time basis and is operated by the resident Pasadena geologist on an appointment basis only. It contains a core splitter and rock saw and shares geotechnical instruments with the Pasadena core library.

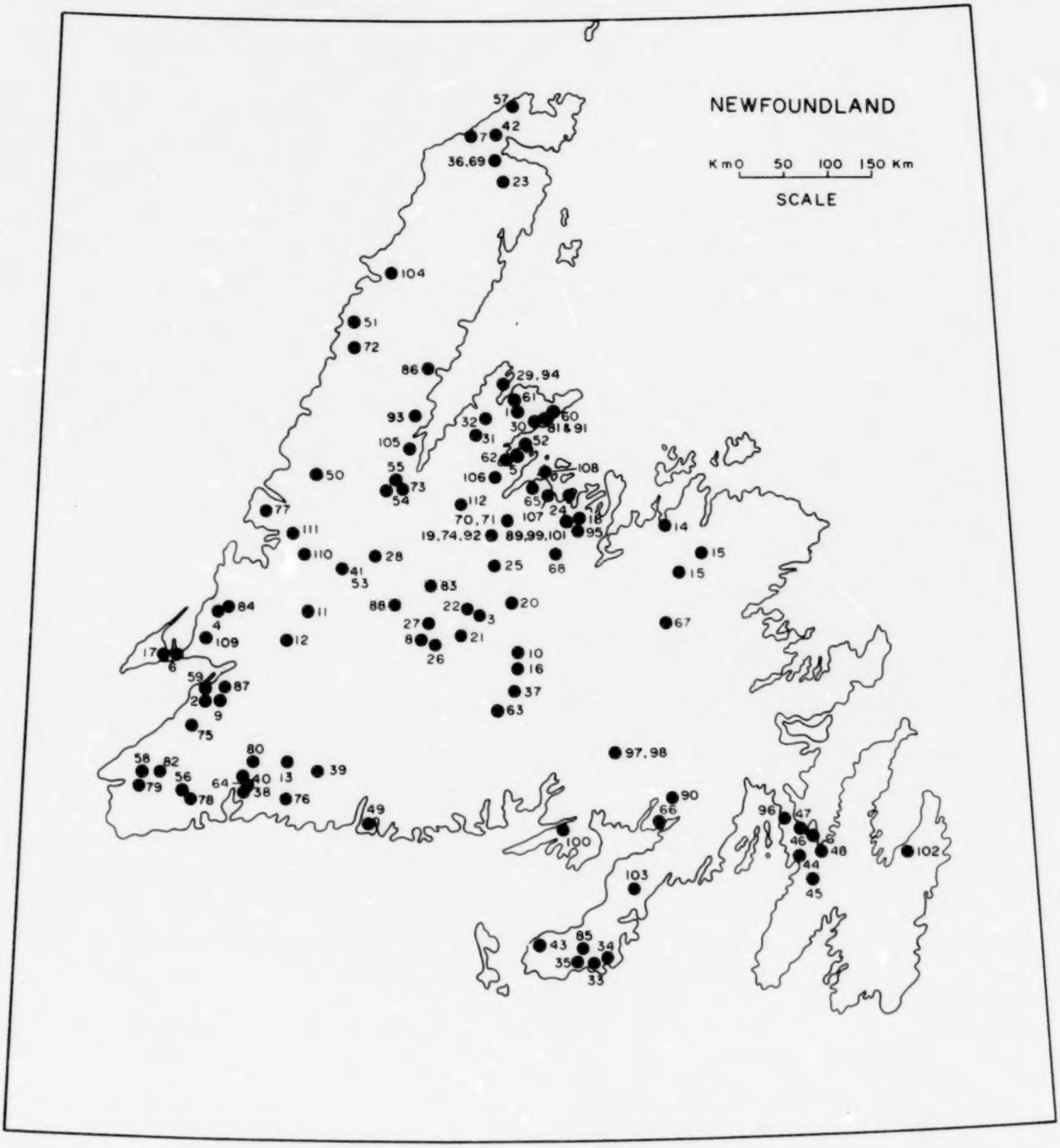

NEWFOUNDLAND
Km 0 50 100 150 Km
SCALE
57
42
7
36,69
23
104
51
72
86
29,94
61
1
60
32
30
81 & 91
31
52
93
105
62
5
108
106
55
73
54
50
112
65
24
18
77
107
70,71
14
111
19,74,92
89,99,101
95
15
110
28
25
68
15
41
53
83
84
4
11
88
22
3
20
27
67
109
12
8
21
26
17
6
10
16
59
87
2
37
9
63
75
97,98
80
58
82
13
39
56
64
40
79
78
38
76
90
49
96
47
66
100
46
6
48
102
44
103
45
85
43
34
35
33

Figure 2. *Core-collection sites, insular Newfoundland.*

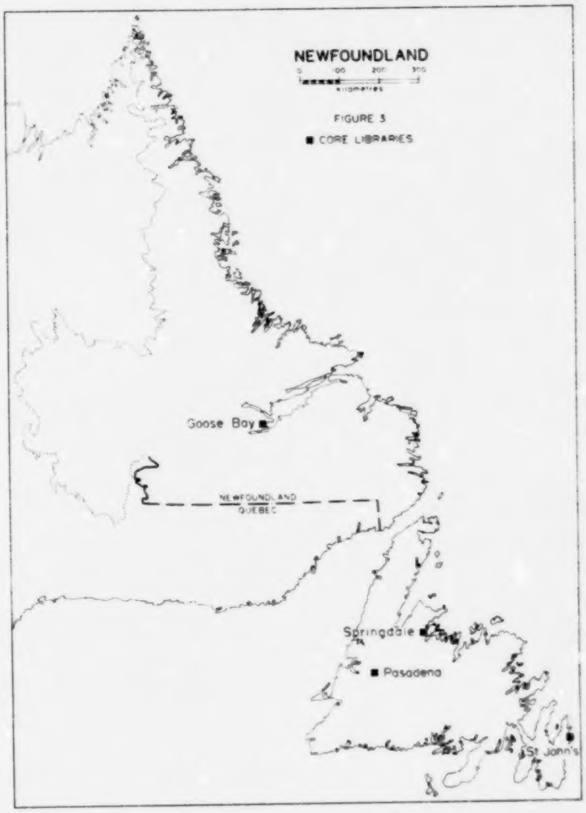


Figure 3. *Core libraries in the province of Newfoundland and Labrador.*

PLANS

The construction of core-storage racks in the proposed Buchans core-storage library will be completed within the 1987-88 fiscal year. It is anticipated that all core available from the Buchans cotenancy of ASARCO and Abitibi-Price will be moved into this building in 1988 when the Department assumes control of the site.

The core-storage program is experiencing a worsening space problem as our core-sample collections continue to increase. The department is taking a two-pronged approach to the space problem by: 1) pursuing expansion to existing facilities and acquiring or renting new core storage facilities, and 2) adopting a policy of selective core collection and reduction.

Preliminary guidelines for core reduction have been drafted and are being applied to our core collection from the Deer Lake Basin as part of a pilot project to test and further refine the guidelines. The results of this exercise are reported elsewhere in this volume.

Table 1. Summary of core collected to date—insular Newfoundland

No.	Company	Year	Property	# of Holes	Total Metres	Storage Location
1	Advocate	1967	Rambler	2	1,193.0	P
2	Amax	1976	Fischells Area	2	1,420.3	P
3	Amoco	1978	Burnt Pond	4	609.6	P
4	Beth Canada	1978	Springer's Hill	10	911.7	P
5	Boylen-Cerro		Colchester	18	1,379.2	P
6	Canadian Ref.	1970	Aguathuna	13	850.1	P
7	Chevron	1979	Eddies Cove	11	481.6	P
8	Cominco-Hansa	1973(?)	Bobby's Pond	5	431.6	P
9	Hooker Chemical	1968	Fischells	1	173.4	SJ
10	HBOG	1978	Gt. Rattling Bk.	11	818.6	P
11	HBOG	1978	Reid Lot 223	5	306.3	P
12	HBOG	1978	Reid Lot 225	2	117.0	P
13	HBOG	1978	Top Pond	1	47.1	P
14	Internat. Mogul	1974	Campbellton Area	15	1,394.5	P
15	Internat. Mogul	1975	Gander Area	12	708.7	P
16	Minorex	1978	Atlantic Lake	6	439.5	P
17	Nfld. Mines Branch		Port au Port	?	811.5	P
18	Noranda	1972	Point Leamington	3	265.8	P
19	Noranda	1973	Gullbridge	1	54.9	P
20	Noranda	1975	Leonard's Lake	3	388.6	P

Table 1. *(Continued)*

No.	Company	Year	Property	# of Holes	Total Metres	Storage Location
21	Noranda	1975-78	Tally Pond	2	489.2	P
22	Noranda	1978	Burnt Pond	2	165.0	P
08	Noranda	1978	Bobby's Pond	4	320.6	P
23	Shell Can. Res.	1975-76	Main Brook Area	32	1,859.3	P
24	Texas Gulf	1975	Seal Bay	8	1,104.9	P
19	Gullbridge Mines	?	Gullbridge	213	12,473.9	P
25	Consol. Morr.	1976	Lake Bond	2	419.1	P
26	L.M. & E.	?	Lake Ambrose	6	647.7	SJ
27	Kerr Addison	1974-75	Victoria Area	5	655.3	P
28	Shawmont	1977-78	Hinds Brook	28	822.9	SJ
29	Advocate	?	Priests Showing	8	774.8	P
30	Advocate	?	Nippers Harbour	7	946.1	P
31	Advocate	1976	West Pond	3	144.7	P
32	Advocate	1975	Flatwater Pond	11	907.6	P
33	ALCAN	?	St. Lawrence	?	8,153.4	SJ
34	D.S. Robertson	?	Mt. Margaret Area	?	4,463.8	SJ
35	D.S. Robertson	?	Lawn Area	?		SJ
36	Noranda	?	Round Pond Area	?	?	P
37	RIOCANEX	1976	Cold Spring Pond	1	30.0	SJ
38	Falconbridge	1979	Strickland Property	?	4,427.2	P
39	Falconbridge	1981	Burgeo Road	16	1,059.2	P
40	Long Lac Min.	1968	Strickland Property	18	975.3	P
41	Minorex	1978-80	Deer Lake	25	1,993.3	P
42	U.S. Borax	1979	Hidden Pond	11	237.6	P
43	Nfld. Mines Branch	1960's	Fortune (Silica)	3	199.9	SJ
44	Nfld. Mines Branch	1960's	Long Harbour (Silica)	6	232.5	SJ
45	Nfld. Mines Branch	1960's	Argentia (Silica)	11	731.6	SJ
46	Nfld. Mines Branch	1960's	Thornlea (Silica)	6	230.9	SJ
47	Nfld. Mines Branch	1960's	Bellevue (Silica)	7	187.1	SJ
48	Nfld. Mines Branch	1960's	Long Cove (Silica)	4	164.1	SJ
49	Nfld. Mines Branch	1960's	Grey River (Silica)	6	256.2	SJ
50	Nfld. Mines Branch	1960's	Bonne Bay (Silica)	4	197.2	SJ
51	U.S. Borax	1981	Daniels Harbour	2	804.6	P
52	Minorex	1981	Silverdale	7	203.6	P
53	Minorex	1979-80	Deer Lake	?	109.7	P
54+	Westfield Minerals	1978-81	Deer Lake	130	8,314.9	P
55	Northgate Expl.	1979	Deer Lake	16	2,511.5	P
56	RIOCANEX	1978-81	Cape Ray	171	20,461.0	P
57	Essex	1981	Watts Bight	4	609.6	P
58	Shell Can. Res.	1980	Codroy Valley	6	890.0	P
59	Flintkote	1979-80	Flat Bay	?	3,214.0	P
60+	Newmont	1981	Tilt Cove	6	864.1	P
61	Rambler Mines	?	Ming Mine	64	9,150.0	P
62	Brinex	?	Whalesback	235	12,226.0	S
63	RIOCANEX	1976	Great Burnt Lake	9	1,463.0	P
64	St. Joe Can.	1982	Big Pond	9	707.0	P
65	Billiton	1981	Ghost Pond	3	668.0	P
66+	Esso Minerals	1982	Ackley Granite	5	280.0	SJ
67	HBOG	1980	Gander Lake South	7	296.1	P
68	HBOG	1980	New Bay Pond	6	356.8	P
69	NAREX ORE SEARCH	1983	Round Pond	21	402.3	P
70	U.S. Borax	1983	Handcamp	7	683.8	P
71	Falconbridge	1979	Handcamp	9	730.6	P
72	Eldorado Nuclear	1979	Portland Creek	1	113.1	P
73	Westfield Minerals	1978	Wigwam Brook	12	576.0	P

Table 1. *(Continued)*

No.	Company	Year	Property	# of Holes	Total Metres	Storage Location
74	Dupont Canada Expl.	1983	Gullbridge	2	312.0	P
75	Nfld. Mines Branch	1983	Robinson's River	1	343.2	P
76-80	Confidential Storage	1983-5	Southwest Nfld.	49	7,769.0	P
81+	Rio Algom	1984	Burtons Pond	6	517.6	P
82+	Getty Mines	1984	Anguille Mountains	2	297.0	P
83+	Can. Nickel Co. Ltd.	1982-3	Badger Area	22	1,767.9	P
84	Asamera Inc.	1984	Bluff Head	7	1,101.5	P
85	BP Minerals Ltd.	1974	Burin Peninsula	11	1,188.7	SJ
86	Nfld. & Lab. Hydro	1977-82	Cat Arm	10	1,417.3	P
87+	Pronto Exploration	1980	Barachois Brook	2	977.8	P
88	Noranda	1983	A.N.D. Charter-JB	10	1,072.8	P
89+	Noranda	1971-84	Central Nfld.	50	11,068.3	SJ
90+	Rio Algom	1985	Ackley Granite	3	333.7	P
91+	Rio Algom	1986	Burtons Pond	2	202.2	P
92+	Esso Minerals	1985	Gullbridge	2	129.0	P
93+	BP-Selco	1985-6	Sops Arm-Rattling Brook	16	1,613.2	P
94	Baie Verte Mines	1978	West Pit	7	840.2	P
95	Getty Mines	1982	Frozen Ocean Pond	3	352.0	P
96	Tasu Resources	1983	La Manche	3	312.3	SJ
97	Kidd Creek Mines	1985	Great Gull Pond	5	568.9	SJ
98	Falconbridge	1986	Bay D'Espoir Highway	4	397.5	SJ
99+	Noranda	1986	Central Nfld.	6	1,422.0	SJ
100+	Noranda	1985	Hermitage Area	4	1,257.0	SJ
101	CAN-MET	1985	Point Leamington	3	342.9	SJ
102	Nfld. Minerals Ltd.	1967-9	Manuels Oval Mine	47	3,243.0	SJ
103	Novamin Resources Inc.	1986	Stewart Option	4	822.1	SJ
62	Brinex	1968	Whalesback	60	Condensed	S
104	Brinex	1976-79	Port au Choix	10	581.0	S
105	Noranda	1977-79	Sop's Arm	32	1,393.1	S
106	Brinex	1966	Duck Pond	4	599.7	S
106	Brinex	1969	Vein Pond	2	237.6	S
106	Brinex	1981	Catchers Pond	4	440.0	S
106	Brinex	1978-80	Davies Pond	10	1,220.8	S
106	Brinex	1978	Halls Bay	5	666.6	S
106	Brinex	1980	Lobot Lake	2	235.8	S
106	Brinex	1962	Muir Pond	6	564.0	S
106	Brinex	1964	Lady Pond	7	835.6	S
106	Brinex	1964	Brown's Pond	3	313.5	S
106	Brinex	1966	Road Shear	3	624.4	S
106	Brinex	1967-69	Rendell Jackman	9	1,137.6	S
106	Brinex	1967-69	Sullivan Pond	16	1,978.2	S
106	Brinex	1968-69	Sterling Property	51	9,584.9	S
106	Brinex	1969	Buckshee Pond	4	513.5	S
106	Brinex	1970	Colchester Pond	10	1,539.3	S
107	Brinex	1977	Ghost Pond	3	293.9	S
107	Brinex	1967	Roberts Arm	3	446.9	S
107	Brinex	1961	Round Pond	5	934.9	S
107	Brinex	1970	Crescent Lake	5	430.4	S
108	Brinex	1980-82	Oil Island	10	1,566.7	S
108	Brinex	1983	Long Island	4	749.0	S
12	Brinex	1978	Glover Island	5	248.6	S
109	Brinex	1975	Table Mountain	4	184.5	S
17	Brinex	1973-75	Port au Port	59	5,978.8	S
110	Brinex	1974	Raft Pond	10	915.8	S
111	Brinex	1966	Bonne Bay	6	471.2	S

Table 1. *(Concluded)*

No.	Company	Year	Property	# of Holes	Total Metres	Storage Location
112	Brinex	1961-76	Indian Pond	16	1,818.7	S
105	U.S. Borax	1985-86	Unknown Brook	18	2,551.0	S
105	U.S. Borax	1986	Corner Brook Pond	1	----	S
105	U.S. Borax	1986	Taylor Pond	2	243.7	S
	OTHER				20,757.0	S, P
	TOTAL				233,433.6	

P —Pasadena Core Library
SJ—St. John's Core Library
S —Springdale Core Library

+ Temporary Confidential Storage

Table 2. Summary of core collected to date—Labrador

No.	Company	Year	Property	# of Holes	Total Metres	Storage Location
1	American Metal Co.	1954	Green Pond	3	16.7	GB
2	BRINEX	1972	Seal Lake	19	1,333.5	GB
3	Canadian Nickel Co.	1978-80	Moran Lake	30	2,103.1	GB
4	Mokta Can. Ltd.	1965	Moran Lake	8	220.9	GB
5	Northgate Explor. Ltd.	1980	Lake Melville	8	652.2	GB
6	Placer Devel. Ltd.	1980-81	Banana Lake	11	655.3	GB
7	RIOCANEX	1961	Ten Mile Lake	4	197.5	P
8	Shell Can. Res.	1977-79	Moran Lake	61	3,822.2	GB
9	Shell Can. Res.	1977	Sylvia Lake	3	99.4	GB
10	Shell Can. Res.	1977	Madsen Lake	2	114.8	GB
11	Nfld. and Lab. Hydro	?	Gull Island		1,037.8	GB
12	L. M. & E. Ltd.	1979-84	Labrador Trough	38	1,513.0	GB
13	Brinex	1969	Makkovik Area	9	1,600.0	GB
				Total	13,366.4	

GB—Goose Bay Library
P—Pasadena Library

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, pages 453-455

MINERAL OCCURRENCE DATA SYSTEM

C.F. O'Driscoll, J. Smith and G. Stapleton
Mineral Deposits Section

The Mineral Occurrence Data System (MODS) is a two-part project designed to offer an efficient information service on all the mineral occurrences in Newfoundland and Labrador. It consists of a manual Mineral Inventory File and a computerized Mineral Index.

The Mineral Inventory File is part of the National Mineral Inventory and consists of mineral-occurrence descriptions that summarize all data on known mineral occurrences in the province. The file presently contains approximately 3,500 descriptions, including all mineral occurrences for the Island of Newfoundland (Figure 1) and selected areas in Labrador (Figure 2). The file and topographic location maps have been microfiched and duplicates are available upon request.

At present, the Mineral Inventory File for the Island of Newfoundland is being updated. This file was started in 1978, and since then, much new geological mapping and exploration have been carried out and many new occurrences have been discovered. Updates were done in the past only on land tenure and major mineral occurrences. Areas that have been updated over this past year include a major part of 12B and the White Bay area of 12H. It is hoped that all mineral occurrences for the Island of Newfoundland will be updated over the next year.

Compilation in Labrador is continuing in the southern Labrador Trough. We anticipate that with additional compilers, most areas in Labrador will be completed in the next year and prior compilations will be updated.

Mineral-occurrence maps that have updated geological bases have been published at a 1:250,000 scale and are available upon request. In addition selected areas have been published at 1:50,000 and 1:100,000 scales. These maps contain locations, a listing and a brief description of the occurrences. During the next year 1:250,000 mineral-occurrence maps will be released for areas 1M and 12A.

The computerized Mineral Index contains information selectively extracted from the Mineral Inventory File. The purpose of the index is to organize important data so that a wide variety of retrievals can be made. It is presently being transferred from the Newfoundland and Labrador Computer Services, where it has previously resided, to the Division's computing system. Work will be done on the file over the next year in order to make it more accessible to people who want to use it.

The manual Mineral Inventory File is used as a quick reference to specific deposits. Exploration company personnel frequently request information on a particular mineral showing or prospect. This is particularly true of those companies new to the province or those moving into new areas. Generally, this preliminary research is done at the Department of Mines by government personnel. However, since a large part of the file has been microfiched, it is available to all companies at a reasonable cost.

The Mineral Inventory File is used daily by government geologists in land-use planning. Advice is given to various departments of government in establishing wilderness areas, hydro developments, provincial and national parks, and any other developments that may conflict with future mineral exploration and development. In addition, municipal councils and the Department of Municipal Affairs are advised of the location, extent, and nature of mineral deposits in specific areas, so that new housing and commercial developments, municipal parks, water reservoirs and sewage-disposal systems can be located, where possible, in areas of low mineral potential.

Copies of the file are made available to the various agencies of the federal government such as the Mineral Policy Sector and the Geological Survey of Canada. These are then adapted to the National Mineral Inventory, MINSYS and CANMINDEX.

The file is available to anyone who is researching mineral deposits in the province. It is useful to students who are writing papers on specific mineral deposits and to company and government personnel who are writing proposals for future work, or preparing information brochures about particular areas.

Using computers, the retrieval capability of the Mineral Index is optimized and complex retrievals can be made that would be virtually impossible if a manual system were used.

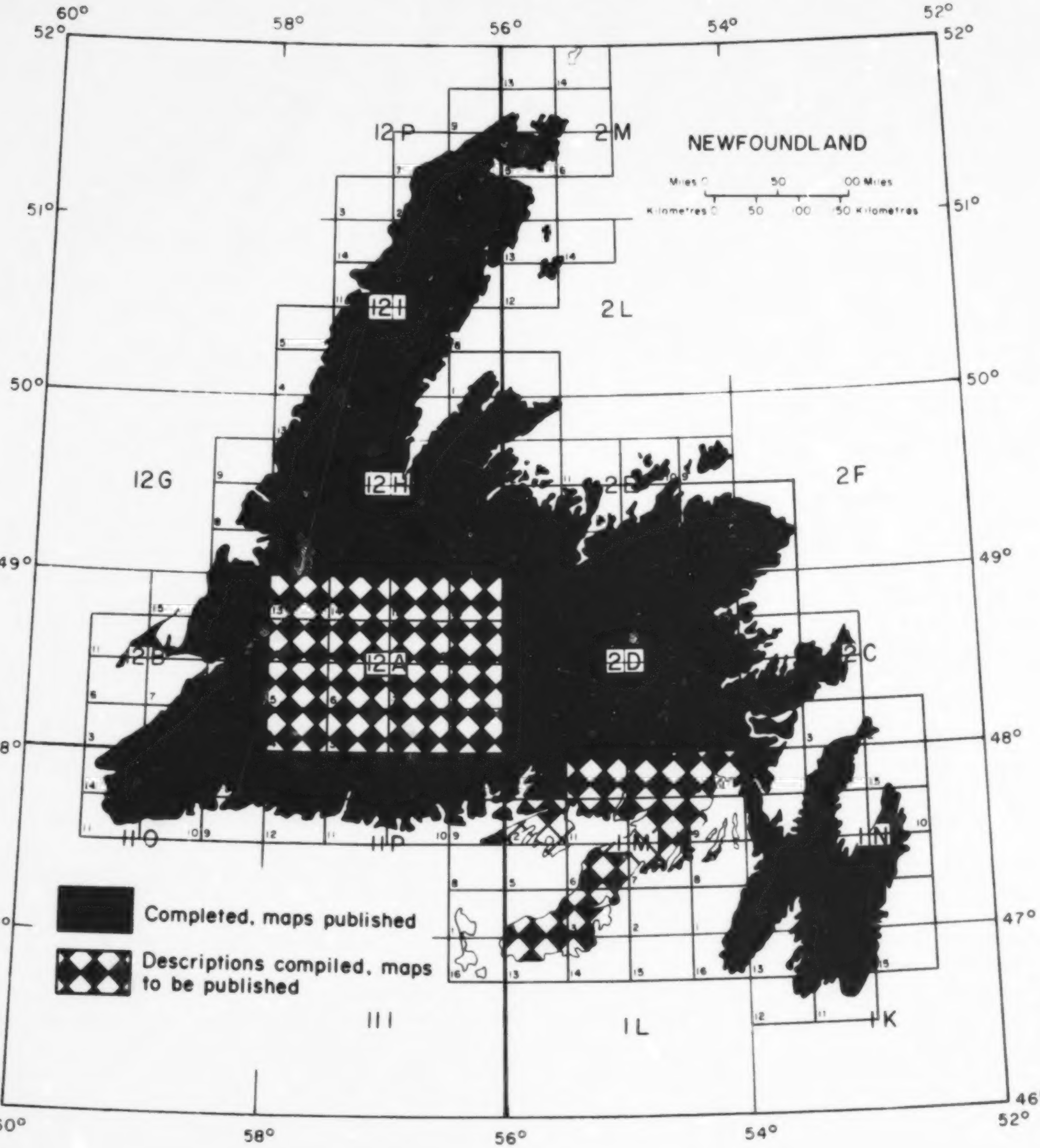

60°
52°
58°
56°
54°
52°
52°
51°
51°
50°
50°
49°
49°
48°
48°
47°
47°
46°
46°
60°
58°
56°
54°
52°
NEWFOUNDLAND
Miles 0 50 100 Miles
Kilometres 0 50 100 150 Kilometres
12P
2M
12I
2L
12H
12G
2E
2F
12B
12A
2D
2C
11O
11P
1M
1N
11I
1L
1K
Completed, maps published
Descriptions compiled, maps to be published

Figure 1. *Index map for Mineral Occurrence Data System project, insular Newfoundland.*

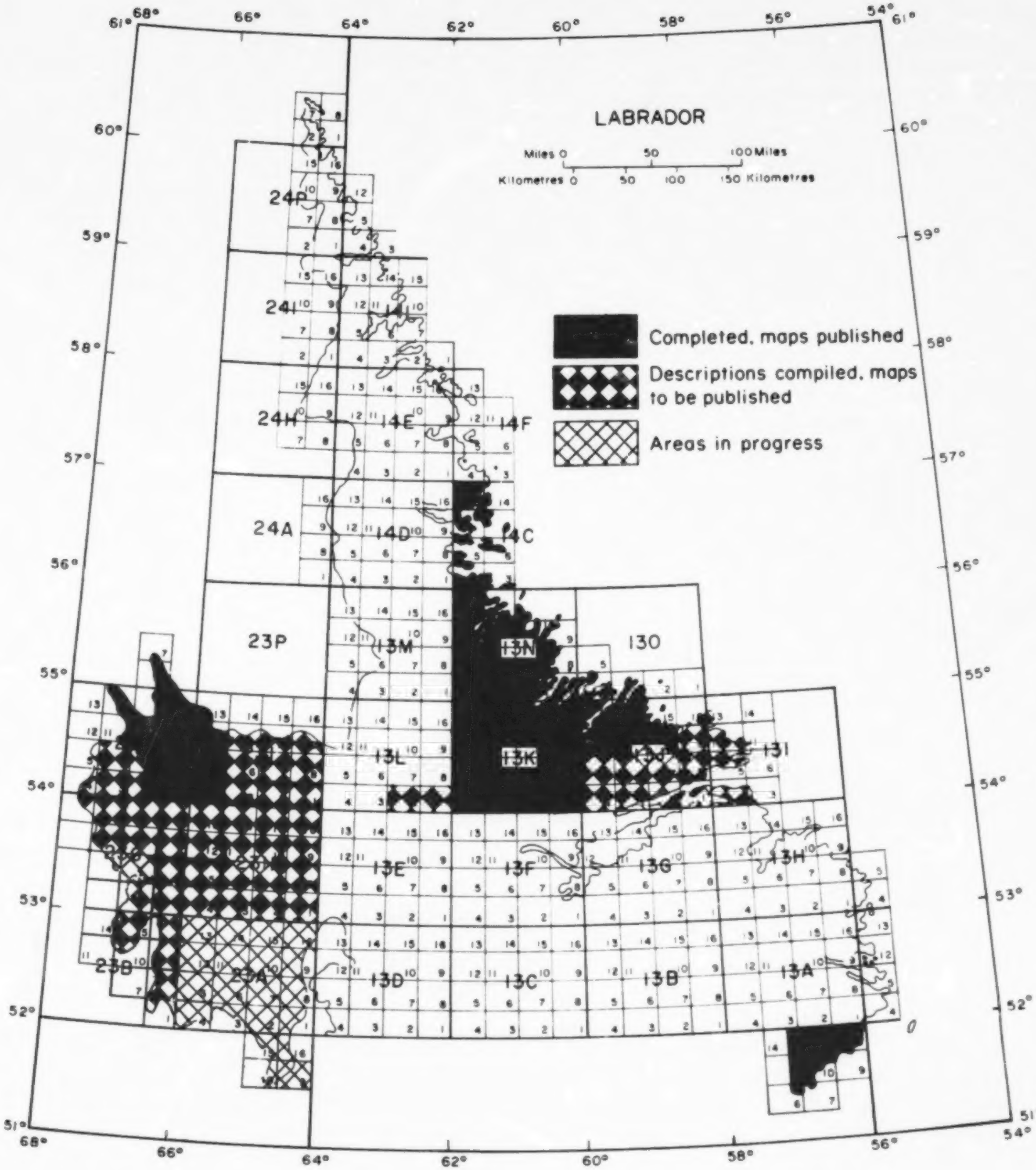

LABRADOR
Miles 0 50 100 Miles
Kilometres 0 50 100 150 Kilometres
Completed, maps published
Descriptions compiled, maps to be published
Areas in progress
24P
24I
24H
24A
23P
23B
23A
14E
14F
14D
14C
13M
13N
13O
13L
13K
13J
13I
13E
13F
13G
13H
13D
13C
13B
13A
68°
66°
64°
62°
60°
58°
56°
54°
61°
60°
59°
58°
57°
56°
55°
54°
53°
52°
51°

Figure 2. *Index map for Mineral Occurrence Data System project, Labrador.*

Current Research (1988) Newfoundland Department of Mines.
Mineral Development Division, Report 88-1, page 456

GEOSCAN–THE NATIONAL DATABASE FOR GEOLOGICAL INFORMATION

Catherine Patey
Publications and Information Section

GEOSCAN is a computerized bibliographic database of Canadian-produced and/or Canada-related geoscience documents.

The Newfoundland Department of Mines is one of the ten agencies that index documents for input into this database. Our Mineral Assessment Report Library files and mineral inventory cards are the sources of our indexed documents. Other agencies, e.g., the Geological Survey of Canada and the Earth Physics Branch of the Canada Department of Energy, Mines and Resources, also produce and index documents that concern this province.

In 1982, the National GEOSCAN Centre, which manages GEOSCAN, implemented a new software system, and most of the old records were converted to a new format.

During the past year, detailed modifications of almost one half of the converted assessment-file records were made online.

All of the 92,600 GEOSCAN records from across Canada, including those concerning this province, are available through online computer searches at the Geological Survey of Canada Library in Ottawa, and in St. John's at our Publications and Information Section.

Current Research (1988) Newfoundland Department of Mines, Mineral Development Division, Report 88-1, page 457

MINERAL ASSESSMENT REPORT LIBRARY–MICROFICHE PROJECT

N.L. Mercer
Publications and Information Section

The Mineral Development Division maintains a geological and mineral-resource-assessment file system, which is referred to as the 'Mineral Assessment Report Library'. This library presently consists of approximately 9,000 geological and geochemical reports, maps, journal articles and mineral-assessment files, making them the largest and most comprehensive single collection of geoscience documents about Newfoundland and Labrador.

As a result of the high level of mineral exploration activity experienced during the late 1970's and early 1980's throughout the province, the amount of new data submitted increased substantially. New information is now available on many of the old and numerous new mineral occurrences in the province. Much more is now known about the geology and mineral potential of various regions, both on the island and in Labrador.

The Mineral Development Division has also conducted a large number of field projects over the past few years. This has resulted in the publication of many new geological reports, maps and open files, as well as the results of numerous geochemical surveys and surficial and aggregate-resource studies.

Mining and exploration companies, prospectors, geotechnical and consultant firms, government agencies, universities, libraries and the general public are continually making use of the geofiles. Requests for information have increased substantially in the past few years.

During the past seven years, the Publications and Information Section has been putting all of the good-quality mineral-assessment reports on microfiche. This provides a much more efficient system of maintaining the geofiles. Requests for information are processed more rapidly and easily, with relatively inexpensive charges for microfiche.

The microfiche project involves weekly filming of batches of reports. The reports are cross-checked before filming for quality, content and reproducibility. Two microfiche originals are made and cataloged for each file. Filing follows the standard NTS system. Duplicates can be copied from the original fiche upon demand. One set of fiche originals is stored offsite at the Torbay Core Library for security and protection from fire.

Microfiche sets of mineral-assessment reports covering all 1:250,000 NTS map sheets in insular Newfoundland are available along with microfiche sets for many of the Newfoundland General Series reports. Several releases have also been made for microfiche sets of mineral-assessment reports covering all 1:250,000 NTS map sheets in Labrador.

Work on the Labrador mineral-assessment reports is continuing and we expect to make several more releases of duplicate sets of microfiche by this fall. Labrador has been the focus of our attention this year, and we are hoping to complete this phase of the project in 1988. We are also hoping in 1988 to release microfiche copies of files that have become non-confidential since the initial release.

The total cost of mineral-assessment reports that are available as microfiche duplicates is $2,081.00

During 1987, we also continued placing the mineral-occurrence reports on microfiche and making them available. Presently, mineral-occurrence reports for NTS areas 1N, 2C, 2D, 2E, 2F, 2L, 2M, 11O, 11P, 12A, 12B, 12G, 12H, 12I, 12P, 13K, 13N and 14C are available. Further releases will be made as staff in the Mineral Deposits Section complete new NTS areas.

For information, please contact Norman Mercer (709) 576-3159. We look forward to your comments and suggestions in improving our microfiche system.

ACKNOWLEDGMENTS

Cathy van Nostrand is thanked for her excellent work on the microfiche project this past year.

The Department of Mines also acknowledges the continued participation and cooperation of Ches Hapgood and staff of the Micrographics Section, Newfoundland Department of Public Works and Services, especially in filming and duplicating the geofiles.

Stratigraphic and metallogenic relationships along the unconformity between Archean granite basement and the early Proterozoic Moran Lake Group, central Labrador[1]

D.H.C. Wilton[2], C.S. MacDougall[2], L.M. MacKenzie[2], and C. Pumphrey[2]

Wilton, D.H.C., MacDougall, C.S., MacKenzie, L.M., and Pumphrey, C., Stratigraphic and metallogenic relationships along the unconformity between Archean granite basement and the early Proterozoic Moran Lake Group, central Labrador; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 277-282, 1988.

Abstract

A well exposed unconformity marks the contact between the Warren Creek Formation of the early Proterozoic Moran Lake Group and the underlying basement granitoids of the Archean Kanairiktok Intrusive Suite. The contact zone is the locus for a number of epigenetic quartz (±carbonate) galena-sphalerite chalcopyrite vein systems. A series of transects was completed across the contact zone in order to further define the zone and examine the potential for additional lead-zinc mineralization. Galena-bearing quartz veins were found at only one new locality; the unconformity itself was encountered at four localities.

Résumé

Une discordance bien exposée délimite le contact entre la formation de Warren Creek du groupe de Moran Lake datant du Protérozoïque inférieur et les granitoïdes de socle sous-jacents de la série de roches intrusives de Kanairiktok d'âge archéen. Dans la zone de contact se trouvent un nombre de systèmes filoniens épigénétiques de galène, sphalérite et chalcopyrite à quartz (+carbonate). Une série de transects a été tracée à travers la zone de contact afin de mieux définir la zone et d'analyser le potentiel de minéralisations supplémentaires de plomb et de zinc. On n'a trouvé des filons de quartz renfermant de la galène qu'à un seul endroit nouveau: la discordance elle-même a été observée à quatre endroits.

---

[1] Contribution to Canada-Newfoundland Mineral Development Agreement 1984-1989. Project carried by Geological Survey of Canada, Mineral Resources Division.

[2] Department of Earth Sciences; Centre for Earth Resources Research Memorial University of Newfoundland, St. John's, Nfld., A1B 3X5

Copper occurrences in the Bruce River Group, Central Mineral Belt of Labrador[1]

Derek H. C. Wilton[2]

Wilton, D.H.C., Copper occurrences in the Bruce River Group, Central Mineral Belt of Labrador; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 291-297, 1988.

Abstract

The middle Proterozoic Bruce River Group supracrustal sequence contains copper (± zinc and/or lead) occurrences localized within faults, fractures and/or shear zones. The most intensive mineralization occurs within the stratigraphically lower sedimentary units of the Bruce River Group due to the more inhomogeneous rheological properties of these units compared to the upper, dominantly felsic, volcanic rocks. The brittle deformation which produced pathways, and hence depositional sites, for base metal-bearing fluids was presumably produced during the Grenvillian Orogeny. Chemical data indicate that the fluids were enriched essentially in Cu, Zn, Pb, Fe, S, SiO_2, and $CaCO_3$.

Résumé

La séquence supracorticale du Protérozoïque moyen du groupe de Bruce River contient des manifestations de cuivre (±zinc et /ou plomb) localisées dans des failles, des fractures et des zones de cisaillement ou les deux. La minéralisation la plus forte se produit dans les unités sédimentaires stratigraphiquement inférieures du groupe de Bruce River due aux propriétés rhéologiques les plus hétérogènes de ces unités comparées à celles des roches volcaniques, surtout felsiques supérieures. La déformation fragile qui produit des passages et donc des sites de dépôt pour des fluides contenant des métaux communs, a probablement été produite pendant l'orogénie de Grenville. Des données chimiques indiquent que les fluides ont été enrichis essentiellement de Cu, de Zn, de Pb, de Fe, de S, de SiO_2 et de $CaCO_3$.

---

[1] Contribution to the Canada — New Foundland Mineral Development Agreement 1984-1989. Project carried by Geological Survey of Canada, Mineral Resources Division.

[2] Department of Earth Sciences/Centre for Earth Resources Research
Memorial University of Newfoundland, St. John's, Nfld. A1B 3X5

The Grenville Province boundary in the Burnt Lake area, Central Mineral Belt of Labrador[1]

Leonard M. MacKenzie and Derek H. C. Wilton[2]

MacKenzie, L.M. and Wilton, D.H.C., The Grenville Province boundary in the Burnt Lake area, Central Mineral Belt of Labrador; in *Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 233-237, 1988.*

Abstract

The felsic volcanic and sedimentary rocks of the Upper Aillik Group and post-tectonic granites in the Burnt Lake area of Labrador have variously been included within and outside of the Grenville Tectonic Province. Some authors have even suggested that the Grenville Front passes through the Burnt Lake area (and consequently through several radioactive occurrences in the region). This paper presents new structural and Rb-Sr isotopic data which indicate that the Burnt Lake area has been strongly affected by the Grenvillian Orogeny and as such belongs within the Grenville Province.

Résumé

Dans des études antérieures, les roches volcaniques et sédimentaires felsiques du groupe supérieur d'Aillik et les granites post-tectoniques de la région du lac Burnt dans le Labrador ont été, selon le cas, inclus ou exclus de la province tectonique de Grenville. Selon certains auteurs, le front de Grenville traverserait la région du lac Burnt (et par conséquent traverserait les gisements de roches radioactives de cette région). Dans le présent exposé, de nouvelles données structurales et isotopiques (Rb-Sr) indiquent que la région du lac Burnt a été très touchée par l'orogénèse de Grenville et que, de ce fait, elle fait partie de la province de Grenville.

---

[1] Contribution to Canada-Newfoundland Mineral Development Agreement 1984-1989 Project carried by Geological Survey of Canada, Mineral Resources Division.

[2] Department of Earth Sciences/Centre for Earth Resources Research Memorial University of Newfoundland, St. John's, Nfld. A1B 3X5

Geology of radioactive zones in the Round Pond area, Labrador[1]

Craig S. MacDougall[2] and Derek H. C. Wilton[2]

MacDougall, C.S. and Wilton, D.H.C., Geology of radioactive zones in the Round Pond area, Labrador; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 271-275, 1988.

Abstract

Narrow, linear radioactive zones with sphalerite, and minor galena, chalcopyrite, molybdenite, fluorite and precious metals occur in the Round Pond area of the Central Mineral Belt of Labrador within the early Proterozoic Upper Aillik Group. Uranium contents are generally less than 1 % and occur as pitchblende inclusions in amphibole crystals and/or as grains associated with apatite, sphene and Fe-Ti oxides. Mineralization occurs in fractures and breccia zones both along lithological contacts between, and within, rhyolite and amphibolite. The mineralizing event was apparently epigenetic with respect to the hosting Upper Aillik Group.

Résumé

D'étroites zones radioactives linéaires contenant de la sphalérite, ainsi que, dans une moindre mesure, de la galène, de la chalcopyrite, de la molybdénite, de la fluorite et des métaux précieux se trouvent dans la région de Round Pond, dans la zone minérale centrale du Labrador, au sein du groupe supérieur d'Aillik datant du Protérozoïque inférieur. Les teneurs en uranium atteignent en général moins de 1 % et se manifestent sous forme d'inclusions de pechblende à l'intérieur des cristaux d'amphibole ou de grains associés à l'apatite, la sphène et les oxydes de Fe et Ti, ou les deux. La minéralisation s'est produite dans des fractures et des zones de brèche le long de contacts lithologiques entre la rhyolite et l'amphibolite et à l'intérieur de celles-ci. Quant à ce qui a trait au groupe supérieur encaissant d'Aillik, il semble qu'il se soit agi d'une minéralisation de nature probablement épigénétique.

---

[1] Contribution to Canada-Newfoundland Mineral Development Agreement 1984-1989. Project carried by Geological Survey of Canada, Mineral Resources Division.

[2] Department of Earth Sciences, Centre for Earth Resources Research Memorial University of Newfoundland, St. John's, Nfld. A1B 3X5

Stratigraphy of the Warren Creek Formation, Moran Lake Group, Central Mineral Belt of Labrador[1]

Jon W. North[2] and Derek H.C. Wilton[2]

North, J.W. and Wilton, D.H.C., Stratigraphy of the Warren Creek Formation, Moran Lake Group, Central Mineral Belt of Labrador; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 123-128, 1988.

Abstract

The early Proterozoic Moran Lake Group unconformably overlies Archean granitoid basement in the Croteau Lake area of central Labrador. The group is composed of the Warren Creek Formation and the Joe Pond Formation. The Warren Creek Formation can be divided into two members. The lower member overlies the basement granitoids and consists mainly of green sandstone and siltstone with interbedded dolostone, chert and quartz arenite. The upper member contains graphitic black shale with greywackes and grey siltstone, and minor banded iron-formation, arkose and vesicular basalt. The shale contains some syngenetic pyrite interbeds with lesser sphalerite, chalcopyrite and pyrrhotite. The uppermost unit in the upper member is a buff to white pebbly arkose. The massive and pillowed basalt of the Joe Pond Formation conformably overlies the Warren Creek Formation. A basal conglomerate of the middle Proterozoic Bruce River Group unconformably overlies both formations of the Moran Lake Group.

Résumé

Le groupe de Moran Lake du Protérozoïque inférieur recouvre en discordance le socle granitoïde de l'Archéen dans la région du lac Croteau au centre du Labrador. Le groupe est composé de la formation de Warren Creek et de la formation de Joe Pond. La formation de Warren Creek peut être divisée en deux membres. Le membre inférieur recouvre les roches granitoïdes du socle et consiste principalement de grès et de microgrès verts auxquels sont intercalées des roches sédimentaires formées de dolomie détritique du chert et du quartz sédimentaire. Le membre supérieur contient du schistes argileux noir de nature graphitique avec des grauwackes et du microgrès gris et, dans une moindre mesure, une formation ferrifère rubanée, de l'arcose et du basalte vésiculaire. Le schiste argileux contient des interstratifications sulfurées syngénétiques et, de petites quantités de sphalérite, de chalcopyrite et de pyrrhotite. L'unité supérieure du membre supérieur est une arkose caillouteuse dont la couleur varie de chamois à blanc. Les basaltes massifs et en coussins de la formation de Joe Pond recouvrent en concordance la formation de Warren Creek. Un conglomérat basal du groupe de Bruce River du Protéropzoïque moyen recouvre de façon discordante les deux formations du groupe de Moran Lake.

---

[1] Contribution to Canada-Newfoundland Mineral Development Agreement 1984-1989.

[2] Department of Earth Sciences/Centre for Earth Resources Research, Memorial University of Newfoundland, St. John's, Nfld. A1B 3X5

The Grenville Front thrust belt in western Labrador[1]

Jeroen van Gool[2], Dennis Brown[2], Tom Calon[2], and Toby Rivers[2]

van Gool, J., Brown, D., Calon, T., and Rivers, T., The Grenville Front thrust belt in western Labrador; in Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 245-253, 1988.

Abstract

The Grenville Front in western Labrador is the northwestern margin of a thin-skinned thrust belt with considerable basement involvement. The belt consists of a stack of thrust sheets, with Archean basement tectonically interleaved with Lower Proterozoic cover rocks, emplaced on the adjacent Superior foreland in a northwest directed thrust movement during the Grenvillian Orogeny.

The present level of exposure forms an oblique section through the belt. The metamorphic grade increases across the strike of the belt from lower greenschist in the northwest to middle amphibolite facies in the structurally higher thrust sheets in the southeast, and also along strike from northeast to southwest.

The style of deformation varies, depending upon lithology, metamorphic grade and position in the stack. Thrust sheets some tens to several hundreds of metres in true thickness are separated by high strain ductile shear zones. The thrust sheets are internally deformed by folds and imbricate thrusts, some of which have been identified as duplex structures.

Résumé

Le front de Grenville dans l'ouest du Labrador correspond à la bordure nord-ouest d'une zone de charriage à croûte mince au sein de laquelle le socle joue un rôle inportant. La zone est composée d'une superposition de nappes de charriage dans lesquelles des roches archéennes sont tectoniquement intercalées avec des roches de couverture de Protérozoïque inférieur qui ont été mises en place sur l'avant-pays contigu de la province du lac Supérieur dans un mouvement de charriage dirigé vers le nord-ouest survenu au cours de l'orogenèse grenvillienne.

La partie exposée forme une coupe oblique qui traverse la zone. Le degré de métamorphisme des roches augmente à travers la direction générale suivie par la zone, passant du faciès des schistes verts inférieur dans le nord-ouest au faciès des amphibolites intermédiaire dans les nappes de charriage structuralement plus élevées dans le sud-est, et aussi le long de la direction, du nord-est au sud-ouest.

Le mode de déformation varie selon la lithologie, le degré de métamorphisme des roches et l'emplacement au sein de la superposition. Des zones de cisaillement ductiles très déformées séparent les nappes de charriage mesurant quelques dizaines à plusieurs centaines de mètres d'épaisseur réelle. Ces dernières sont déformées à l'intérieur par des plis et des nappes de charriage imbriquées dont quelques-unes sont duplex.

---

[1] Contribution to Canada-Newfoundland Mineral Development Agreement 1984-1989. Project carried by Geological Survey of Canada, Mineral Resources Division.

[2] Centre for Earth Resources Research, Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X5.

Glacial studies in Labrador[1]

R.D. Klassen and F.J. Thompson

Klassen, R.D. and Thompson, F.J., Glacial studies in Labrador; in *Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 109-116, 1988.*

Abstract

Regional studies in Labrador support earlier work which indicated a complex history of shifting ice flow based on glacial striae and dispersal of glacial erratics. In the Wabush region, youngest striae indicate flow towards the southeast, consistent with glacial moulding of bedrock. Older striae record flow to the south-southwest in the west, and to the south-southeast in the south. Erratics derived from Labrador Trough, north of the Grenville Structural Province, are widespread. To the west they are rare and are associated with transport during the earliest (SSW) phase of flow. To the south they are abundant and appear to have been transported during the two last phases of flow (SSE, SE). Recently-discovered stratigraphic sections contain distinct till units and interglacial organic deposits that promise a record to match the complex glacial history recorded by surficial geology.

Résumé

Des études régionales effectuées au Labrador confirment des travaux antérieurs qui ont établi une histoire complexe d'écoulement variable des glaces en se basant sur l'observation des stries glaciaires et de la dispersion des blocs erratiques. Dans la région de Wabush, les stries les plus récentes indiquent un écoulement vers le sud-est, conséquent avec le modelé glaciaire du socle. Des stries plus anciennes indiquent un écoulement vers le sud-sud-ouest à l'ouest, et vers le sud-sud-est au sud. Les roches erratiques dérivées de la fosse du Labrador, au nord de la province structurale de Grenville, sont très nombreuses. À l'ouest, elles sont rares et associées au transport de matériaux durant la phase d'écoulement la plus ancienne (SSO). Au sud, elles sont abondantes et semblent avoir été transportées durant les deux dernières phases d'écoulement (SSE, SE). Des coupes stratigraphiques récemment découvertes contiennent des unités distinctives de till et des dépôts organiques interglaciaires qui permettront sans doute d'établir une chronostratigraphie tout aussi importante que l'histoire glaciaire complexe documentée par la géologie des formations en surface.

---

[1] **Contribution to the Canada-Newfoundland Mineral Development Agreement 1984-1989. Project carried by Geological Survey of Canada, Terrain Sciences Division.**

Mafic-ultramafic occurrences in metasedimentary rocks of southwestern Newfoundland[1]

D. Fox[2] and J.T. Van Berkel[3]

Fox, D. and Van Berkel, J.T., Mafic-ultramafic occurrences in metasedimentary rocks of southwestern Newfoundland; in Current Research, Part B, Geological Survey of Canada, Paper 88-1B, p. 41-48, 1988.

Abstract

In southwestern Newfoundland, thin layers and inclusions of mafic-ultramafic rocks occur within a quartzitic and semipelitic unit of a larger metasedimentary belt. The ultramafic rocks are generally altered to assemblages of serpentine, talc, carbonate, chlorite and tremolite-actinolite. Thin chromite layers and relict (igneous?) olivine are locally observed. The mafic rocks are metagabbros consisting of both massive and layered types and contain plagioclase, hornblende, minor quartz and secondary chlorite and zoisite.

Tectonic disruption of the mafic-ultramafic rocks is interpreted to occur in a wide shear zone which locally develops the "block in matrix" feature typically ascribed to mélange zones. The previous history and origin of the mafic-ultramafic rocks is uncertain. Regionally, however, they lie along strike of mafic-ultramafic rocks of the Glover Island complex to the north and the Long Range mafic-ultramafic complex to the south, which are both interpreted as being part of an ophiolite suite.

Résumé

Dans le sud-ouest de Terre-Neuve, on rencontre de minces couches d'inclusions de roches mafiques et ultramafiques à l'intérieur d'une unité quartzitique et semi-pélitique qui fait partie d'une vaste zone métasédimentaire. Généralement, les roches ultramafiques ont été altérées et ont donné naissance à des assemblages de serpentine, talc, carbonates, chlorite et de trémolite et actinolite. On observe localement de minces couches de chromite et des cristaux relictes (ignés?) d'olivine. Les roches mafiques sont des métagabbros tantôt massifs, tantôt stratifiés, et contiennent des plagioclases, de la hornblende, des quantités accessoires de quartz et de la chlorite et zoïsite secondaires.

On a interprété les dislocations tectoniques des roches mafiques et ultramafiques comme ayant eu lieu dans une vaste zone de cisaillement qui localemnent présente une structure de « blocs dans une matrice », que l'on attribue généralement aux zones de mélange. On connaît mal l'évolution et l'origine des roches mafiques et ultramafiques. Cependant, à l'échelle régionale, celles-ci suivent la direction des roches mafiques et ultramafiques du complexe de Glover Island au nord et du complexe mafique et ultramafique de Long Range au sud, interprétés tous deux comme faisant partie d'une suite ophiolitique.

---

[1] Contribution to the Canada-Newfoundland Mineral Development Agreement 1984-1989. Project carried by Geological Survey of Canada, Lithosphere and Canadian Shield Division.

[2] Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland, A1B 3X5.

[3] Present address: Institute of Earth Sciences, Free University, P.O. Box 7161, 1007 MC Amsterdam, the Netherlands.

New interpretation of the structural and stratigraphic setting of the Cutwell Group, Notre Dame Bay, Newfoundland[1]

Z.A. Szybinski[2]
Mineral Resources Division

Szybinski, Z.A., New interpretation of the structural and stratigraphic setting of the Cutwell Group, Notre Dame Bay, Newfoundland; in Current Research, Part B, Geological Survey of Canada, Paper 88-1B, p. 263-270, 1988.

Abstract

The rocks of the Cutwell Group record a two stage structural history. The first deformation (D1) was Silurian or earlier and resulted in north-directed thrusting and folding. Previously-interpreted lithostratigraphic sequences reflect structures related to this deformation. The second deformation (D2) resulted in east-west, dextral, strike-slip faulting, manifested mainly in movement on the Lobster Cove Fault. This deformation involved Silurian rocks and so the latest movement was Silurian or younger.

From stratigraphic sequence within thrust slices, the reconstructed stratigraphy of the Cutwell Group is: 1) a lower mafic to intermediate volcanic member; 2) an intermediate, dominantly felsic, volcanic member; and 3) an upper sedimentary member capped by Caradocian shale. There are no post-Caradocian volcanics in the group.

Volcanogenic sulphide deposits occur mainly within the Long Tickle Formation of the Cutwell Group. Correlation suggests that other felsic volcanic sequences in the Cutwell Group should have a similarly high exploration potential.

Résumé

Les roches du groupe de Cutwell offrent le profil d'une évolution structurale à deux stades. La première déformation (D1) s'est produite au Silurien ou avant et elle a provoqué un charriage et un plissement à direction nord. Des séquences lithostratigraphiques déjà expliquées confirment l'existence de structures liées à cette déformation. La seconde déformation (D2) a causé un décrochement dextre est-ouest qui s'est manifesté surtout par des mouvements sur la faille de Lobster Cove. Cette déformation a affecté des roches siluriennes, c'est pourquoi le dernier mouvement appartient au Silurien ou à une époque plus récente.

À partir d'une séquence stratigraphique comprise dans des lambeaux de charriage, la stratigraphie reconstituée pour le groupe de Cutwell est la suivante: 1) un niveau volcanique inférieur allant de mafique à intermédiaire; 2) un niveau volcanique de type intermédiaire et surtout felsique et 3) un niveau sédimentaire supérieur coiffé par du schiste argileux caradocien. Il n'y a pas de roches volcaniques post-caradociennes dans le groupe.

Des dépôts de sulfure volcanogénique se rencontrent surtout à l'intérieur de la formation de Long Tickle du groupe de Cutwell. Une corrélation suggère que d'autres séquences volcanofelsiques dans le groupe de Cutwell devraient posséder un potentiel d'exploration aussi élevé.

---

[1] Contribution to the Canada-Newfoundland Mineral Development Agreement 1984-1989. Project carried by the Geological Survey of Canada, Mineral Resources Division.

[2] Department of Earth Sciences, Memorial University of Newfoundland, St. John's, Newfoundland, A1B 3X5.

Re-examination of the Frozen Ocean Group: juxtaposed middle Ordovician and Silurian volcanic sequences in central Newfoundland.[1]

H. Scott Swinden[2]

Swinden, H.S., Re-examination of the Frozen Ocean Group: juxtaposed middle Ordovician and Silurian volcanic sequences in central Newfoundland; in *Current Research, Part B, Geological Survey of Canada, Paper 88-1B, p. 221-225, 1988.*

Abstract

The Frozen Ocean Group, as previously defined, is bipartite. The northern part consists of Ordovician pillow lavas and interbedded epiclastic rocks which are tentatively correlated with the Big Lewis Lake basalts of the Wild Bight Group to the north. No felsic volcanic rocks are present. These rocks are not correlated with massive sulphide-bearing sequences in the Wild Bight Group and are not belived to be prospective, although this remains to be tested by whole-rock analyses. The southern part includes red to orange, subaerial rhyolites and mafic volcanic rocks, interpreted as Silurian on the basis of lithological correlations with the Springdale Group to the west. There may be a potential in the southern area for epithermal gold mineralization.

The Frozen Ocean Group name should be dropped. Formal definition of these rocks awaits systematic mapping. No rocks within this sequence are correlatives of the Buchans-Robert's Arm Belt.

Résumé

Le groupe Frozen Ocean, tel qu'il a auparavant été défini, est bipartite. La partie nord se compose de laves en coussins ordoviciennes et de roches épiclastiques interstratifiées qui ont été provisoirement corrélées aux basaltes de Big Lewis Lake du groupe de Wild Bight plus au nord. Aucunes roches volcaniques felsiques ne sont présentes. Ces roches ne sont pas corrélées à des séquences massives riches en sulfures au sein du groupe de Wild Bight et on ne les estime pas prometteuses, bien que ceci reste à démontrer par des analyses effectuées sur des échantillons de roche totale. La partie sud comprend des rhyolites subaériennes dont la couleur varie de rouge à orange, ainsi que des roches volcaniques mafiques, que l'on attribue au Silurien en s'appuyant sur des corrélations lithologiques avec le groupe de Springdale situé plus à l'ouest. Il peut exister un potentiel de minéralisation aurifère épithermal dans la zone sud.

Le nom « Frozen Ocean Group » (groupe de Frozen Ocean) devrait être abandonné. Une définition officielle de ces roches exige une cartographie systématique préalable. À l'intérieur de cette séquence, aucune des roches n'est corrélative de la zone de Buchans et Robert's Arm.

---

[1] Contribution of Canada — Newfoundland Mineral Development Agreement, 1984-1989. Project carried by Geological Survey of Canada, Mineral Resources Division.

[2] c/o Department of Mines, P.O. Box 4750, St. John's, Nfld, A1C 5T7

NOTES

MINERAL DEVELOPMENT DIVISION

B.A. GREENE, *Director*
DOREEN PEAVY, *Secretary to the Director*

ADMINISTRATIVE SUPPORT SERVICES

KAREN DAWSON, *Accounting Clerk*
TED HALL, *Storekeeper (Nfld.)*
KENNETH O'QUINN, *Storekeeper (Lab.)*
SIDNEY PARSONS, *Administrative Assistant (Nfld.)*
WAYNE RYDER, *Senior Administrator*
WAYNE TUTTLE, *Administrative Assistant (Lab.)*

NEWFOUNDLAND MAPPING SECTION

DOUG BOYCE, *Project Geologist*
STEPHEN COLMAN-SADD, *Senior Geologist*
LAWSON DICKSON, *Project Geologist*
JOHN HAYES, *Geologist*
IAN KNIGHT, *Project Geologist*
BRIAN O'BRIEN, *Project Geologist*
SEAN O'BRIEN, *Project Geologist*
PAT O'NEILL, *Project Geologist*

LABRADOR MAPPING SECTION

JIM CONNELLY, *Project Geologist*
LORETTA CRISBY, *Geologist*
CHARLES GOWER, *Project Geologist*
ANDREW KERR, *Project Geologist*
GES NUNN, *Project Geologist*
BRUCE RYAN, *Project Geologist*
ANDRE THOMAS, *Project Geologist*
RICHARD WARDLE, *Senior Geologist*

GEOCHEMISTRY SECTION

JOE ATKINSON, *Computer Programer*
ANN MARIE BOURGEOIS, *Senior Laboratory Assistant*
JAMES BUTLER, *Project Geochemist*
GORDON BUTTON, *Senior Laboratory Assistant*
REX BUTTON, *Senior Laboratory Assistant*
RHONDA COLLINS, *Laboratory Assistant*
PETER DAVENPORT, *Senior Geochemist*
GEOFFREY DAWE, *Chemist*
CHRISTOPHER FINCH, *Chemist*
PETER HARING, *Chemist*
GERALD KILFOIL, *Geophysicist*
JOHN McCONNELL, *Project Geochemist*
HARJIT MISSAN, *Project Geologist, Computer Unit*
LISA NEWMAN, *Geological Technician*
LAWRENCE NOLAN, *Geologist*
KEITH PARSONS, *Systems Analyst*
CHARLES RILEY, *Geochemical Analyst*
HERBERT SKANES, *Laboratory Technician*
HANK WAGENBAUER, *Laboratory Director*
GEORGE WARFORD, *Laboratory Assistant*

MINERAL DEPOSITS SECTION

JUDY BANTON, *WP Operator*
ANNE HOGAN, *Geologist*
AMBROSE HOWSE, *Project Geologist*
BAXTER KEAN, *Project Geologist*
JAMIE MEYER, *Project Geologist*
RANDY MILLER, *Project Geologist*
CYRIL O'DRISCOLL, *Project Geologist*
JIM ROGERS, *Geological Technician*
CINDY SAUNDERS, *Project Geologist*
JANICE SMITH, *Mineral Inventory Geologist*
SCOTT SWINDEN, *Senior Geologist*
GREG STAPLETON, *Mineral Inventory Geologist*
JOHN TUACH, *Project Geologist*

QUATERNARY GEOLOGY SECTION

MARTIN BATTERSON, *Project Geologist*
CHRISTINE BLACKWOOD, *Mineral Assayer*
DANIEL BRAGG, *Project Geologist*
BEVERLY DOWNTON, *Geologist*
FREDERICK KIRBY, *Project Geologist*
DAVE PROUDFOOT, *Senior Geologist*
MARTIN (JERRY) RICKETTS, *Project Geologist*
BYRON SPARKES, *Project Geologist*
LLOYD ST. CROIX, *Geological Technician*
DAVE TAYLOR, *Geologist*

PUBLICATIONS AND INFORMATION SECTION

FRANK BLACKWOOD, *Senior Geologist (Acting)*
KEVIN BREWER, *Public Information Co-ordinator*
KENNETH BYRNE, *Supervisor, Cartographic Services*
STEWART COCHRANE, *Geologist (Pasadena)*
KATHLEEN CONNORS, *Typist and WP Operator*
DEBORAH DOWNEY, *WP Lead Operator*
ALVIN HARRIS, *Project Geologist, Drill Core*
FRED HURLEY, *GEOSCAN Clerk*
RICHARD HYDE, *Editor*
DAVID LEONARD, *Cartographer*
JOANNE MATTHEWS, *WP and Typesetter Operator*
RANDY MEEHAN, *Information Officer*
NORM MERCER, *Mineral Exploration Consultant*
TONY PALTANAVAGE, *Cartographer*
CATHERINE PATEY, *GEOSCAN Geologist*
SUE SACHDEV, *Librarian*
SHARON SHORT, *Cartographer*
KELLY STEINHAUER, *Cartographer*
BEVERLY STRICKLAND, *Typesetter and WP Operator*
CATHERINE VAN NOSTRAND, *Microfiche Clerk*
DES WALSH, *Copy Editor*